VOL. XXXVIII. No. 3 MARCH, 1960

THE STRUCTURAL ENGINEER

THE JOURNAL OF THE
INSTITUTION OF STRUCTURAL ENGINEERS

New Developments in Structural Analysis and Design by Means of the Electronic Computer:—

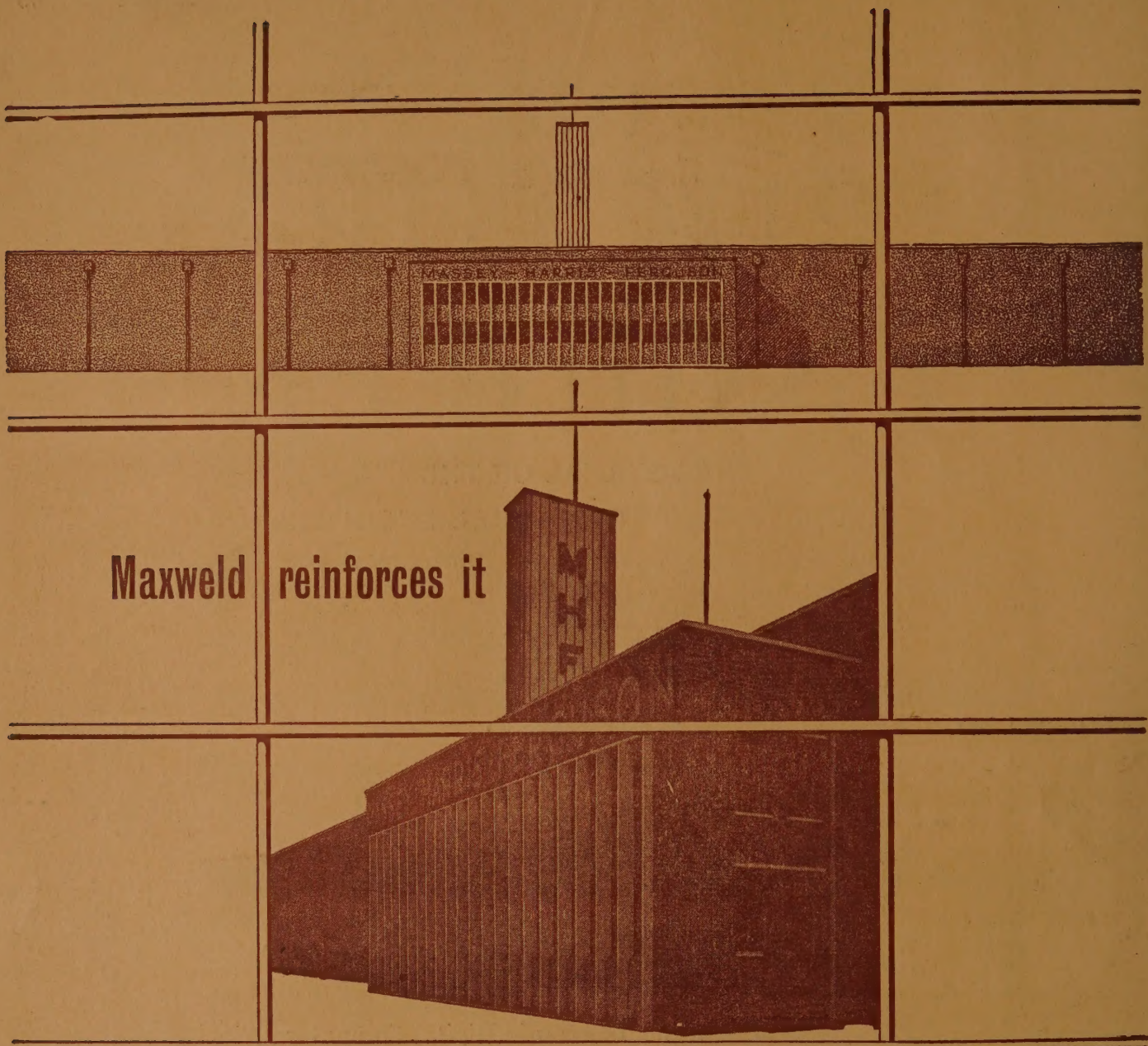
(1) Application of an Electronic Digital Computer to Structural Steel Design
by L. Morgan

(2) The Analysis of Grid Frameworks and Floor Systems by the Electronic Computer
by Dr. E. Lightfoot (Delegate Member of Council) and F. Sawko

(3) Elastic Critical Loads of Multi-bay Pitched Roof Portal Frames with Rigid External Stanchions
by Dr. D. M. Brotton (Associate-Member)

Research for the Concrete Industry
by Dr. A. R. Collins, M.B.E. (Member of Council)

FOUR SHILLINGS AND SIXPENCE



Maxweld reinforces it

The reinforcement fabric used in the Massey-Harris Ferguson factory at Stretford was supplied by Richard Hill. Do you need reinforcements? Then call up the Maxweld man! He can give you all the facts on the type and quantity of fabric you'll need plus a rough idea of the cost. And he's backed by the

Richard Hill Design Service

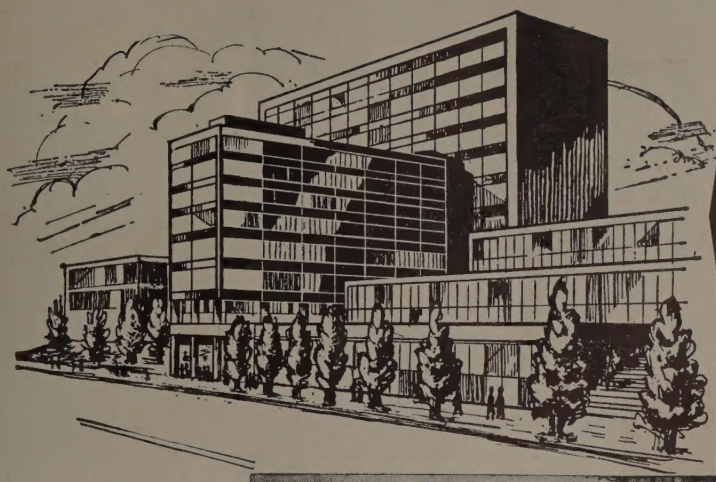
who can then draw up more detailed plans and estimates. You can get him at Middlesbrough (2206), London (Mayfair 3538), Birmingham (Mid. 5625), Manchester (Central 1652), Leeds (2-7540), Bristol (24977), Glasgow (Central 2179), Nottingham (Bulwell 27-8383), Bournemouth (Westbourne 63491). Belfast (29126)

Maxweld fabric

is manufactured by RICHARD HILL LIMITED (Established 1868)

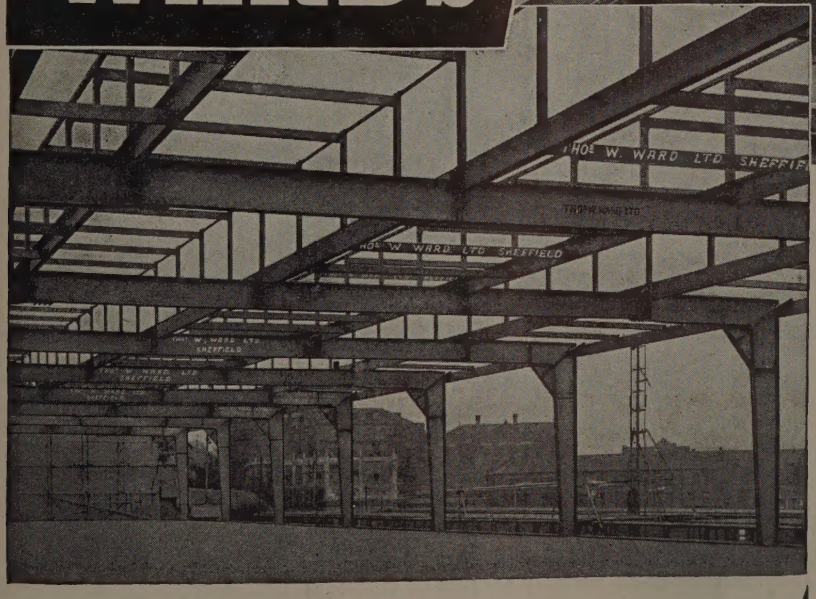
Newport Wire and Rolling Mills, Middlesbrough, Yorkshire. Tel : Middlesbrough 2206

A MEMBER OF THE FIRTH CLEVELAND GROUP



SHEFFIELD COLLEGES OF COMMERCE AND TECHNOLOGY

STRUCTURAL STEELWORK BY WARDS



Wards Structural Steelwork Dept. specialises in the production and erection of steelwork for every kind of building. Among contracts recently undertaken is notably one for the new colleges at Sheffield. The two photographs were taken during course of construction, and are by permission of J. L. Womersley, Esq., Sheffield City Architect; Henry Smith Esq.,A.R.I.C.S., General Manager, Sheffield Public Works Department; Messrs. Gollins, Melvin, Ward & Partners, Chartered Architects.

THOS. W. WARD LTD

ALBION WORKS · SHEFFIELD
PHONE 26311 (22 lines) · GRAMS FORWARD · SHEFFIELD ·
LONDON OFFICE: BRETTENHAM HOUSE
LANCASTER PLACE · STRAND · WC2. PHONE TEM 1515

C.S.24

CAN PROPANE GIVE YOU GREATER OUTPUT?

For the right answer, for the right gas, and for the best service—ask British Oxygen Gases

Does your type of production call for Propane? British Oxygen Gases will give you an unbiased answer. Because British Oxygen supply gases for all purposes, they can help you from experience to choose the most efficient, most economical gas for your particular production needs.

Only British Oxygen Gases has this breadth of experience and only British Oxygen Gases can offer you such a complete delivery service of industrial gases . . . in cylinders, or in bulk from their nation-wide tanker fleet—and lend you storage tanks as well if you need them.

BRITISH OXYGEN GASES LIMITED A BOC Company

SPENCER HOUSE, 27 ST. JAMES'S PLACE, LONDON S.W.1.

You'd have a long way to go
to beat FLOWFORGE*
forge welded
open steel
flooring
* FLOWFORGE
Saves on ....
First cost
Installation
Maintenance
FISHER & LUDLOW LIMITED
FLOORING DIVISION
BORDESLEY WORKS, BIRMINGHAM 12. Tel: VICtoria 2371

The **Demolition & Construction** Co. Ltd.

LONDON · CARDIFF · LIVERPOOL · NEWCASTLE-ON-TYNE

D&C

CIVIL ENGINEERING, BUILDING & PUBLIC WORKS CONTRACTORS

Wythenshawe Swimming Pool is taking shape

Our illustration shows what it will look like when completed later this year. Ultra-modern in design and construction, the pool will incorporate a restaurant, a club room and the very latest heating, ventilating and filtration equipment. The frame and floors will be reinforced concrete and the external surfaces will all be glazed between concrete mullions.

As main contractors, Simon-Carves are making yet another contribution to the campaign for brighter British building. Our comprehensive civil engineering contracting service is at work on schools and colleges, office buildings, mining installations, railway modification schemes and a great variety of industrial plants. We are ready to build to your design or to accept responsibility for every stage of your contract.

Building Wythenshawe Swimming Pool

Architect: Leonard C. Howitt, M.Arch., D.A. (Manc.), Dip.T.P., D.P.A., F.R.I.B.A., M.T.P.I., City Architect, Manchester.

BUILDING AND CIVIL ENGINEERING BY

Simon-Carves Ltd

SIMON ENGINEERING GROUP

CHEADLE HEATH, STOCKPORT

nd at CALCUTTA · JOHANNESBURG · SYDNEY · TORONTO

C 218

WELL INFORMED STRUCTURAL ENGINEERS

READ

The

CONTRACT JOURNAL

published every Thursday, The CONTRACT JOURNAL will bring *you* the latest news of —

- Construction methods, plant and materials
- Major building and civil engineering works at home and abroad
- Professional institutions, trade organisations and commercial undertakings
- Political and legal topics affecting the constructional industries

2/- per copy
Annual subscription:
£5 · 4 · 0d post paid

Specimen copy free on request from

THE CONTRACT JOURNAL COMPANY LIMITED

32 SOUTHWARK BRIDGE ROAD, LONDON S.E.1. Tel. WATERLOO 3411

CJ 71

Automation together with large, comprehensive steel stocks and

MCN. 3427

general 'know-how' enables us to quote even lower and to deliver even more quickly

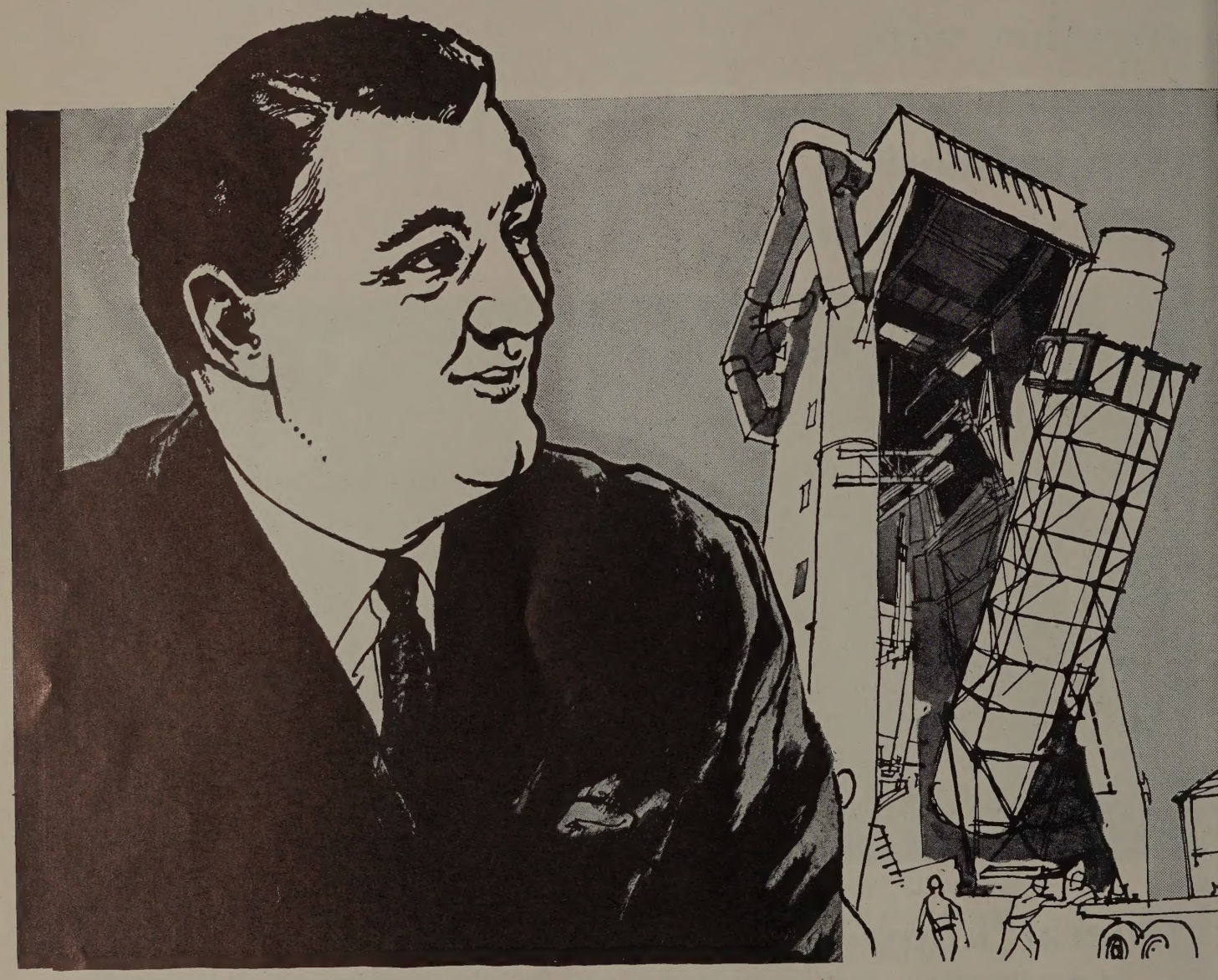
This multiple drilling machine is drilling twelve holes simultaneously. It is part of our fully automatic fabricating plant—one of the largest of its kind in the world.

Banister, Walton

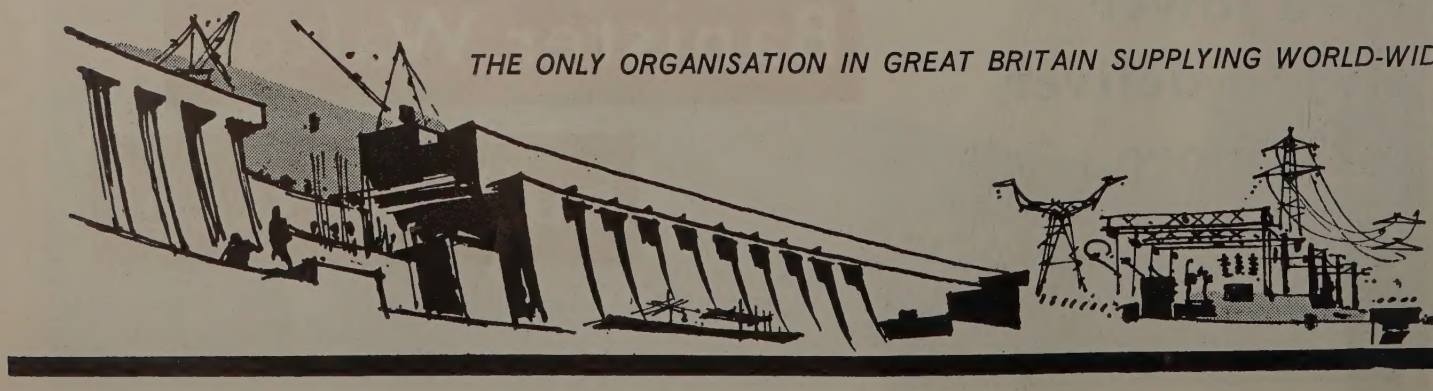
build in steel

BANISTER, WALTON & CO., LTD Structural Steel Engineers and Stockholders MANCHESTER · LONDON · BIRMINGHAM

OIL REFINERY COMPLETED



WOOD, PRITCHETT & PARTNERS LTD



THE ONLY ORGANISATION IN GREAT BRITAIN SUPPLYING WORLD-WID

AHEAD OF SCHEDULE...

OUR SERVICE CAN MAKE THIS A POSSIBILITY

THIS IS THE MODUS OPERANDI . . .

WE PROVIDE–

Productive organisation on site to execute efficiently the working specification of contract, incorporating:—

LABOUR–

Crane, excavator and fork lift truck operators, stenographers, clerks, mechanics, fitters, painters, riggers, production control personnel, warehousemen, welders, carpenters, truck drivers, etc., etc.

EQUIPMENT–

Mobile Cranes, Fork Lift Trucks, Lorries, Compressors, Excavators, Welding Sets, Machinery Tools, Tractors, etc., etc.

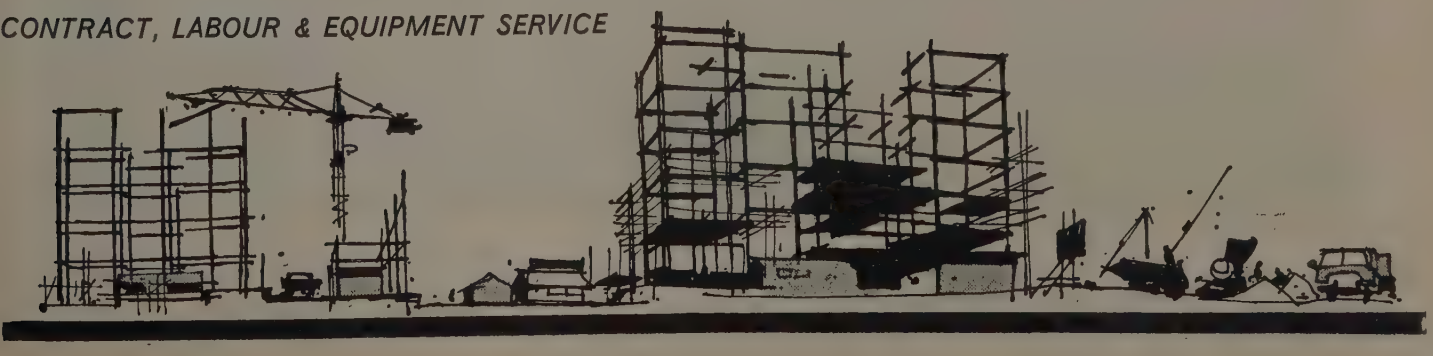
ECONOMICALLY–

Attractive "all-in" hourly rates for men and machinery—home or abroad—designed to reduce contractors' overheads and eliminate contract delays.

FOR FURTHER PARTICULARS OF THE ABOVE SERVICE PLEASE WRITE OR 'PHONE:—

30/38 HAMMERSMITH BROADWAY · LONDON W.6 · RIVerside 2224
MECHQUIP HOUSE · GOLDHAWK ROAD · LONDON W.12 · SHEpherds Bush 4406
CABLE ADDRESS: MECHQUIP · LONDON

CONTRACT, LABOUR & EQUIPMENT SERVICE



DAWNAYS
STEELWORK

Specialists in the design fabrication and erection of riveted and welded steel-framed structures of every description

DAWNAYS LIMITED

BRIDGE & STRUCTURAL ENGINEERS

STEELWORKS RD., BATTERSEA, LONDON, S.W.11.

Telephone: BATTERSEA 2525 (10 lines)

ALSO AT SWANSEA · CARDIFF · WELWYN GARDEN CITY · NORWICH · HULL · SOUTHAMPTON · ROMFORD · VICTORIA STREET, S.W.1

NOT WITH THIS ROOF

An atmosphere full of moisture and acid-laden soot and smoke . . . that is what causes the rapid deterioration of the roofing and cladding of industrial buildings. How to deal with this menace is a problem to which, until recently, there has been no satisfactory solution.

Now there is an answer — ' Corroplast ' corrugated sheets *resist corrosion*. Experience has proved that after many years' exposure in the most severe conditions, ' Corroplast ' sheets do not deteriorate.

These strong, rigid, laminated plastic sheets are economical, too. They last longer than any other sheets, need no maintenance, and are free from breakages in transit.

For roofing and cladding where corrosion is worst, always specify . . .

FOR CONTEMPORARY CLADDING TOO

' Corroplast ' is also ideal as side-cladding for contemporary buildings, giving a most colourful and attractive appearance. Available in three integral shades, or in a range of stove-enamelled finishes.

Reed PAPER GROUP

CORROPLAST

CORRUGATED LAMINATED PLASTIC

Write or phone to:

HOLOPLAST LIMITED SALES OFFICE, DEPT. 30, 2, CAXTON STREET, LONDON, S.W TEL: ABBEY 4866

where weight matters

LYTAG

Lightweight aggregate gives...

Maximum workability

LYTAG gives greater workability for a particular mix than any other lightweight aggregate, because its spherical particles present the minimum surface area to be wetted.

Minimum shrinkage and high early strength

The low water contents of LYTAG concretes lead to reduced drying shrinkages and give high early strengths. Surface finishes obtained on precast concrete units are smooth and pleasing.

High fire resistance with low 'U' values

The combustible content of LYTAG is less than ½%. It will withstand temperatures of up to 1,000°C without damage. At the same time, it provides a 'U' value well below that of ordinary concrete. For example, the 'U' value of a 6" LYTAG structural concrete element would be less than a half that of the same element in dense concrete.

60% Air—100% efficient

LYTAG is produced from pulverised fuel ash by a carefully controlled sintering process. Spherical in shape, it has a slightly roughened surface so providing an excellent key for the adhesion of cement.

Technical literature covering all aspects of LYTAG will be forwarded on request. Write to:

LYTAG LIMITED MANOR WAY, BOREHAM WOOD, HERTFORDSHIRE. Telephone Elstree 2864 A LAING COMPANY

Wherever you may go . . .

East, West, North, South; wherever you go you will find Shell.

We market our products in 130 countries throughout all 5 continents and can supply you with the petroleum products and technical services you need.

Our widespread contacts and long experience of local conditions can help in other ways. By knowing the ropes one can often save people tripping over them. When you deal with Shell, you have associates everywhere.

you can be sure of SHELL **international service**

Unique! Versatile! Economical!

that's

STRAMIT 'MOVAFLUSH'

...THE NEW EASY-TO-ERECT PARTITION

Just consider the outstanding advantages ! Stramit 'Movaflush' Partitions are erected speedily and easily. They have remarkable sound-deadening properties, and afford excellent thermal insulation, as well as a high degree of fire resistance. They also have an attractive flush finish (no unsightly cover-fillets) and offer an exceptionally good surface for decoration. What's more, Stramit ' Movaflush ' Partitions are of completely dry construction and are available in a wide range of sizes. They're rigid, durable and de-mountable. And for all this, they're surprisingly low in price.

For full details fill-in and post coupon—NOW

Please send, without obligation, full details of the new Stramit ' Movaflush ' partition. SE.3

COMPANY .....

ADDRESS .....

.....

For the attention of .....

STRAMIT BOARDS LTD., COWLEY PEACHEY, UXBRIDGE, MIDDLESEX : West Drayton 3751 *(10 lines)*

BUILDING UP SPEED

This is the century which is out to beat the clock. From 5 m.p.h. in one of the "old crocks" to 25,000 m.p.h. by rocket into outer space "Faster and faster" is the slogan of the age, not only for travel but also for production and building.

Nowadays the framework of a building soars into the blue almost in the time it takes to say "prefabrication".

Speed is the essence of modern building and that means prefabricated steel that can be erected quickly on the spot.

Skinningrove specialises in fast deliveries of fabricated steelwork in all shapes and sizes. Personal attention is given to every order which passes through the works. From the time the order reaches the office until it is delivered to the site everything is done to see that the work proceeds quickly.

For fabricated steel it's Skinningrove for speed and service.

SKINNINGROVE IRON CO. LTD.

P. O. BOX No. 1. SALTBURN, YORKSHIRE. TEL: LOFTUS 212

Send for a copy of the new Skinningrove Section and Underground Roof Support booklets which give details of sizes rolled and services etc..

TEST BORINGS

FOR THE UNDERLYING TRUTH

To ensure
THE STABILITY OF FOUNDATIONS AND EARTH WORKS

OBTAIN RELIABLE INFORMATION OF GROUND CONDITIONS

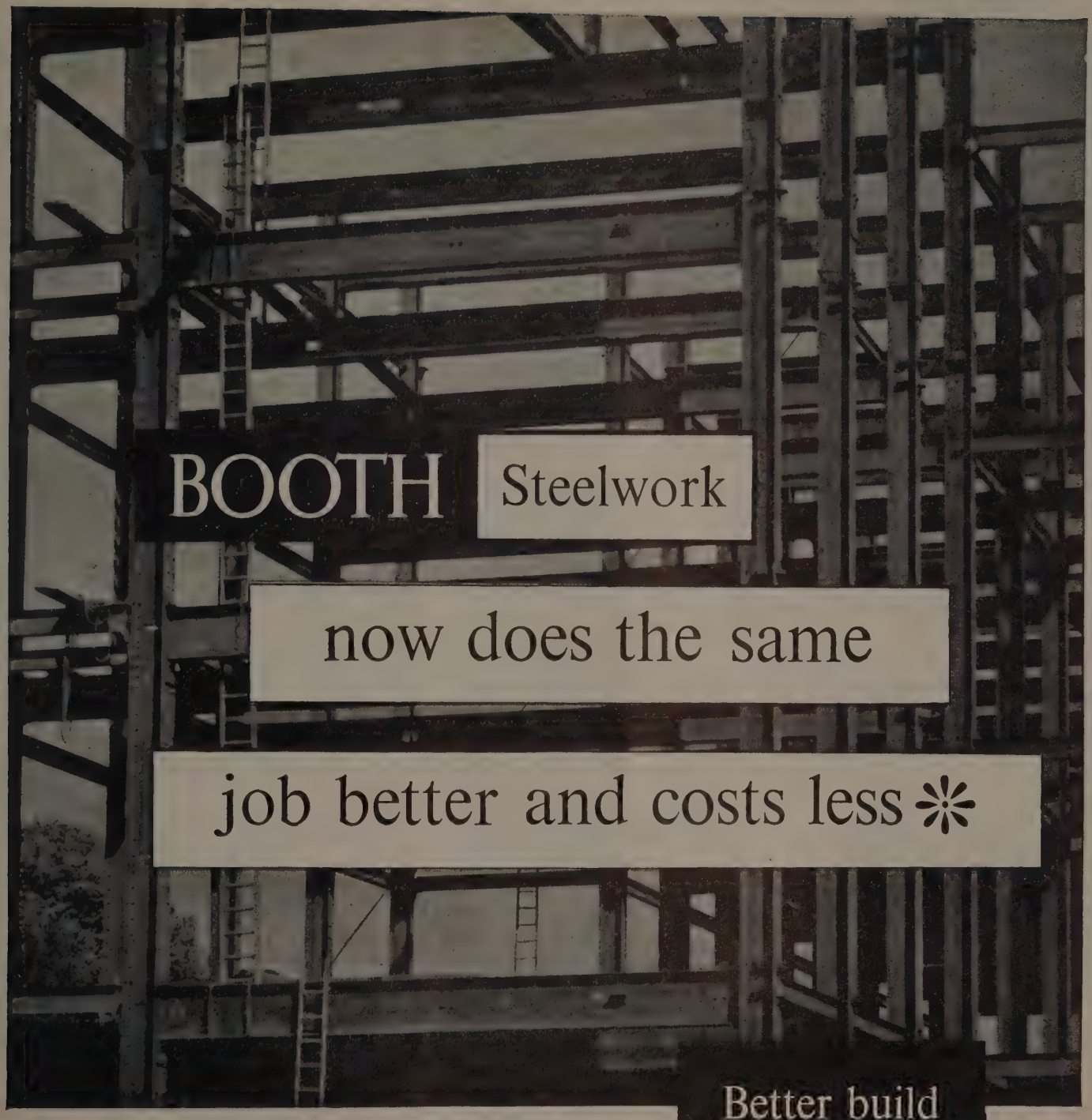
- GEOPHYSICAL SURVEYS
- SOIL SAMPLING & TESTING
- REPORTS ON GROUND CONDITIONS

GROUND EXPLORATIONS LTD
75 UXBRIDGE ROAD, EALING, W.5
Phones: EALing 1145/6 and 9251/2

PIONEERS OF CAST IN SITU PILING

SIMPLEX PILES

SIMPLEX CONCRETE PILES LTD
Palace Chambers, Bridge Street, Westminster, S.W.1
Telephone Nos. TRAfalgar 1165/8/9
Telegrams: SIMPILESCO WESPHONE LONDON



BOOTH Steelwork

now does the same

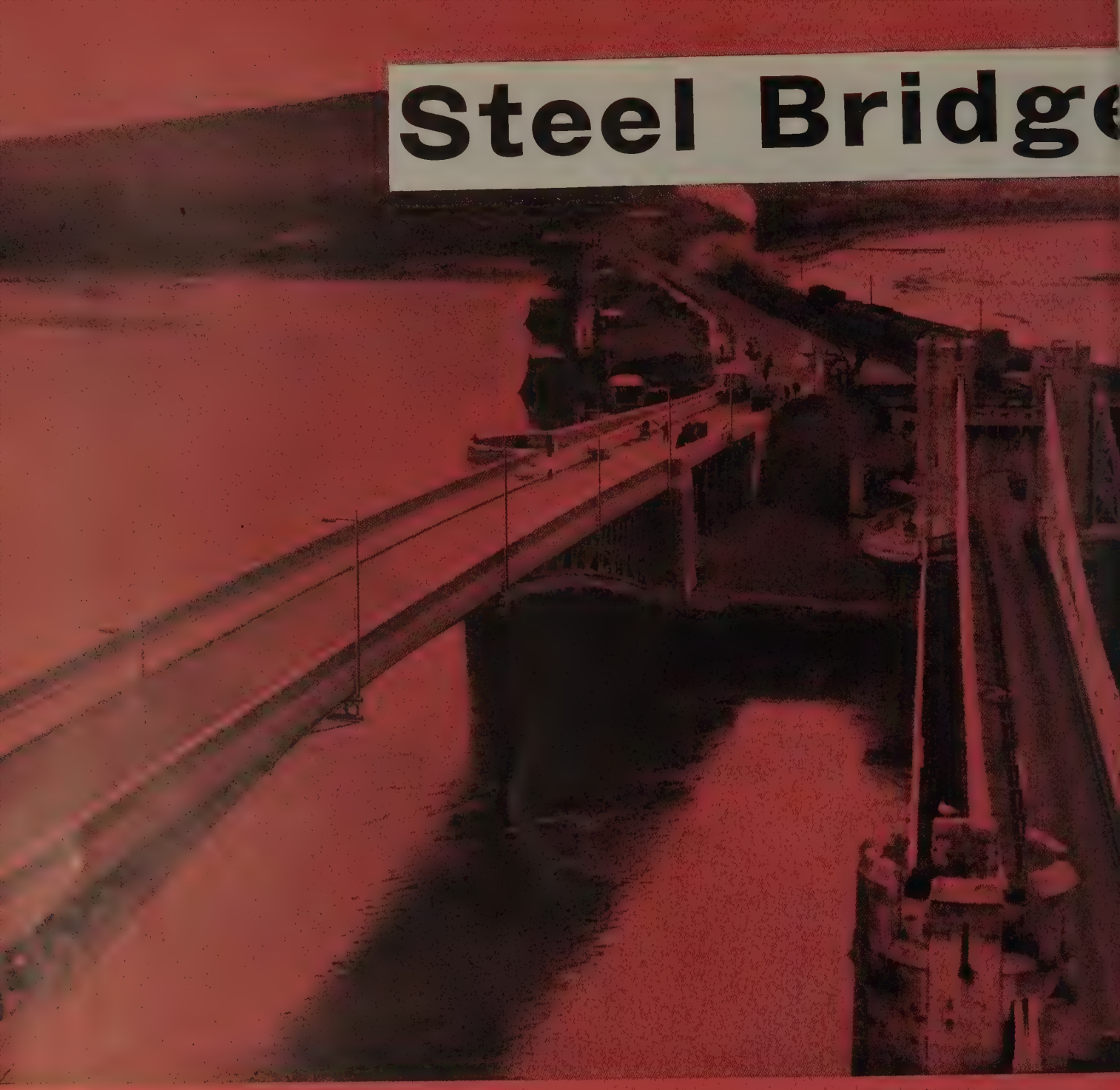
job better and costs less ❊

❊ by taking advantage of the new provisions of BS-449 (1959), worthwhile economies can be effected.

Better build with Booth Steelwork and cut the cost of *your* structure.

JOHN BOOTH & SONS (BOLTON) LTD. HULTON STEELWORKS, BOLTON, Telephone BOLTON 1195.
London: 26 VICTORIA STREET, WESTMINSTER, S.W.1. Telephone ABBey 7162.

Steel Bridge



The new bridge
over the River Conway
N. Wales.

All types of Steel Framed Buildings; Fixed and Opening Bridges; Cranes and Mechanical Engineering work; Dock Gates, Sliding and Floating Caissons; Compressed Air Locks; Hydraulic Machinery; Pipe Lines, Surge Tanks, Sluices and other equipment for Hydro-Electric Projects.

SIR WILLIAM ARROL & C

for Conway . . .

'BOX' *Gate for Falmouth*

A wide range of structures in many and varied locations bear testimony to the craftsmanship of their makers—
Arrol of Glasgow.

'Box' Flap Gate, Queen Elizabeth Dock, Falmouth. ▶

◀ *Overhead crane—Larne N. Ireland.*

◀ *Bridge over River Euphrates, Samawa.*

LTD GLASGOW

Arrol

REWARD

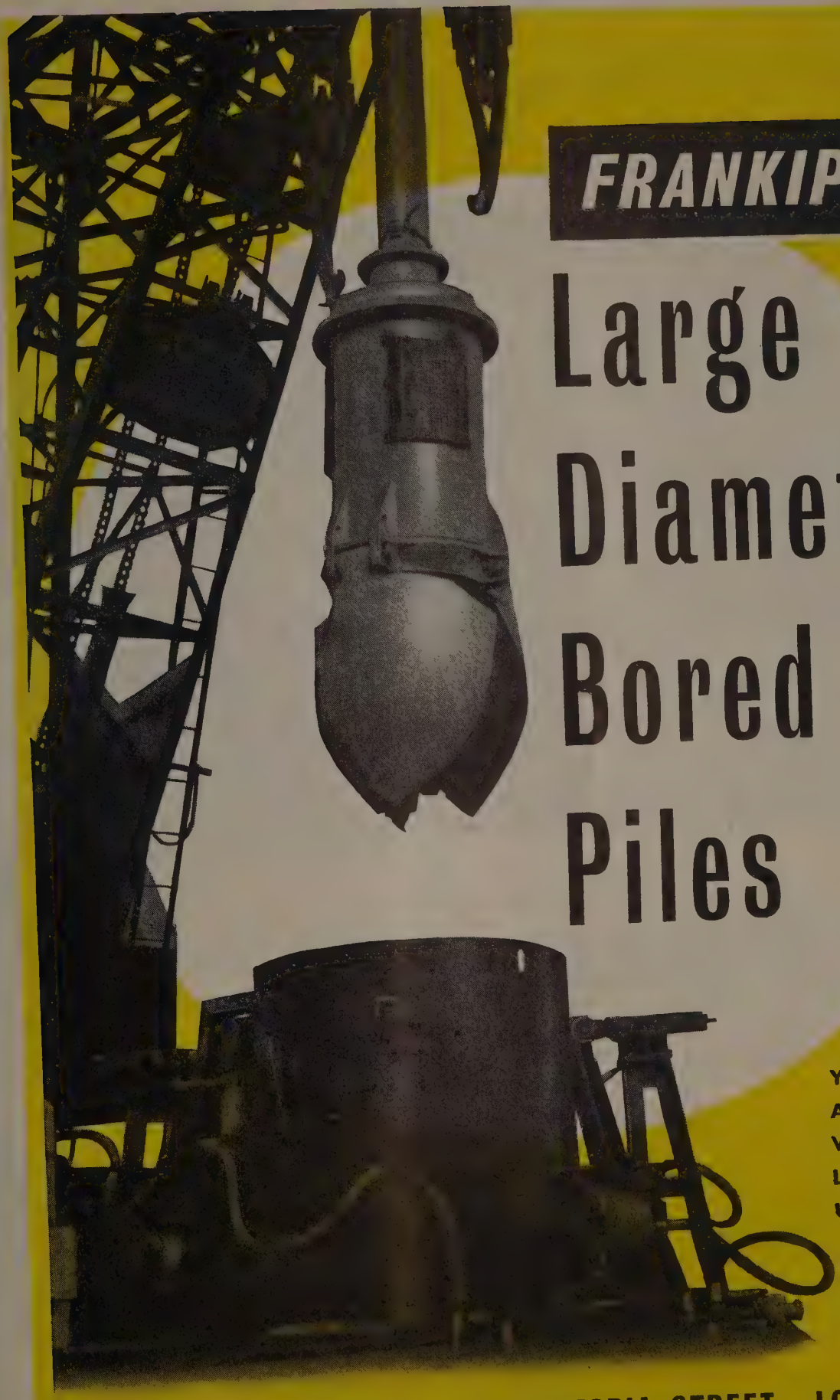
A substantial and well-deserved REWARD has accrued to the above Company Director for his heroic, dogged, rugged—nay, sensible—decision to obtain from **ASSOCIATED LEAD** all his firm's supplies of **RED LEAD PAINTS; RUSTODIAN CALCIUM PLUMBATE PAINTS.** He now moves in an aura of profit and prestige.

This announcement is issued for and on behalf of

ASSOCIATED LEAD MANUFACTURERS LIMITED

CLEMENTS HOUSE, 14 GRESHAM STREET, LONDON, E.C.2. CRESCENT HOUSE, NEWCASTLE. LEAD WORKS LANE, CHESTER

Export enquiries to: Associated Lead Manufacturers Export Co. Ltd., Clements House, 14 Gresham Street, London, E.C.2



FRANKIPILE

Large Diameter Bored Piles

YOUR ENQUIRIES ARE INVITED AND WE WILL SEND LITERATURE UPON REQUEST

FRANKIPILE LIMITED · 39 VICTORIA STREET · LONDON · SW1

TELEPHONE: ABBEY 6006/9

No. 12 OF A SERIES SHOWING TECHNICAL DEVELOPMENTS IN CONCRETE CONSTRUCTION

The first prestressed concrete bridge in New Zealand

Blackett's Road Bridge at Whatawhata

The tender for Blackett's Road Bridge, the first prestressed concrete bridge in New Zealand, was 11 per cent cheaper than the nearest tender by a conventional design. The success of the project has been reflected in over fifty prestressed concrete bridges since erected in New Zealand—all using Johnsons wire. For further details write for leaflet.

Sponsor : Waipa County Council ; Engineer J. N. Anderson.

Design : Pre-stressed Concrete (N.Z.) Ltd.

Contractors : B & B Concrete Co. Ltd. Precast Units.
M & S Construction Co. Erection.

Johnsons were in at the start with wire for prestressed concrete. Their technicians worked with the Continental pioneers in the development of the technique, and today Johnsons wire is specified in a large number of important prestressing contracts.

wire was essential –
Johnsons
of course!

Richard Johnson & Nephew Ltd., Manchester, 11. Telephone: EASt 1431

BUSINESS
LOOKING
UP
-WITH
REEL
OVERHEAD

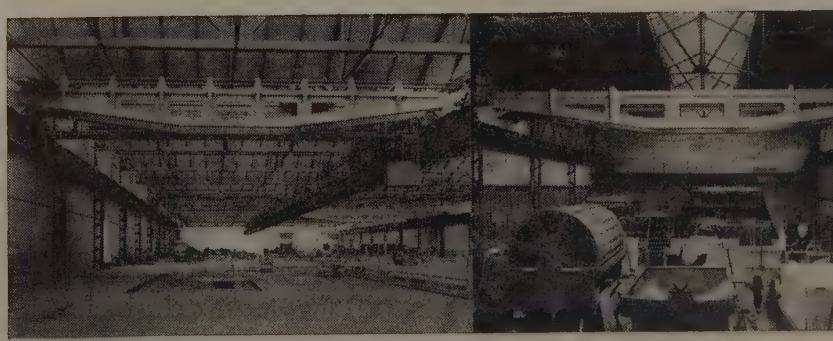
Manufactured under licence fro
Ferrand & Frantz Ing. Villeurbann
British Patent No. 705, 148.

The remarkable performance of REEL overhead cranes has been proved conclusively on hundreds of installations. The new approach to overhead crane design has put REEL well ahead. Conventional boxed lattice frames have been replaced by clean-lined girders providing greater strength and lightness, with a consequent saving in power consumption. REEL Cranes can be carried to within two or three inches of the roofwork and are in capacities to suit your individual requirements. *Full information on request.*

THE BRITISH

"REEL"

OVERHEAD CRANE



BRITISH INDUSTRIAL

ENGINEERING COMPANY (STAFFS) LIMITED

OVERHEAD CRANES FOR INDUSTRY

2 FULLY ROTATING UNDERSLUNG JIB CRANE

This specially designed Electric Overhead Travelling Crane has an underslung jib which revolves in a complete circle, thus giving maximum hook coverage over the floor area, and also enabling loads to be transferred to adjacent bays. The positioning of the controls gives the operator an excellent view of the load. This crane is another example of the flexibility of our design. *When you have a lifting problem—call in John Smiths!*

SPECIAL SERVICE FOR ARCHITECTS AND PLANNING SURVEYORS

Architects and Planning Engineers who are contemplating the incorporation of overhead cranes in new buildings or extensions are invited to write for our Table of Clearances, Weights, Wheel Loads, etc., for Standard E.O.T. Cranes. Advice on all lifting problems gladly supplied by our technical staff without obligation.

John Smith CRANES

JOHN SMITH (KEIGHLEY) LTD
P.O. BOX 21 · THE CRANE WORKS · KEIGHLEY · YORKS.
Telephone: Keighley 5311 (4 lines) Telegrams: Cranes, Keighley
London Office: Buckingham House, 19-21 Palace St. Westminster, London, S.W.1.
Southern Counties Office: Brettenham House, Lancaster Place, London W.C.2

Lorry Garage in Buckinghamshire

Consulting Engineers for Shell Roof: Ove Arup & Partners

TILEMAN

& COMPANY LIMITED

Specialists in the design and construction of reinforced concrete for power and industry

ROMNEY HOUSE, TUFTON STREET, LONDON, S.W.1. Tel: ABBey 1551

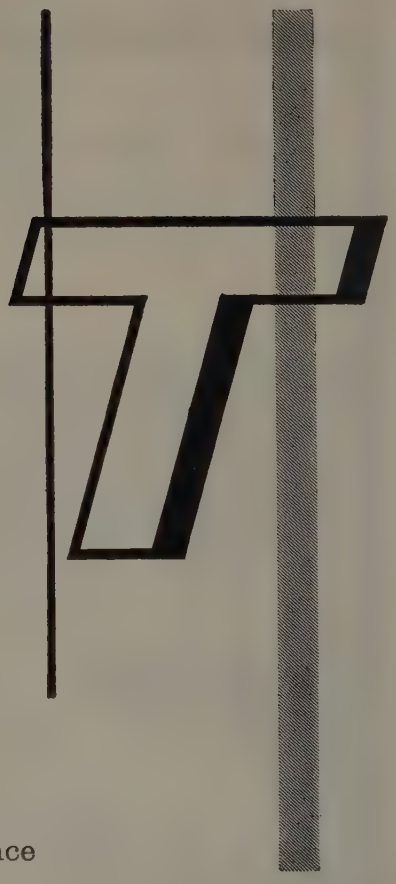
TIL 439

Top quality & service

Site investigations

Bored piling & Foundations

Materials & Structural testing



—Terresearch service has proved its worth—
Terresearch specialists have a wide, practical experience
in all branches of building and civil engineering,
and full resources for carrying out investigations and
research and sound speedy construction.

WE HAVE SUCCESSFULLY CARRIED OUT SUCH WORK FOR:

ATOMIC AND THERMAL POWER STATIONS · AIRFIELD WORKS
RAILWAY WORKS · BRIDGES · ROAD WORKS
MARINE AND HYDRAULIC WORKS · MULTI-STOREY OFFICES
AND APARTMENTS · FACTORIES, etc.

OUR BROCHURE IS YOURS BY REQUEST

Terresearch LIMITED

BUILDING AND CIVIL ENGINEERING LABORATORY
PILING AND FOUNDATION ENGINEERS & CONTRACTORS

RUISLIP ROAD · NORTHOLT · GREENFORD · MIDDLESEX · Telephone: WAXlow 6241-2

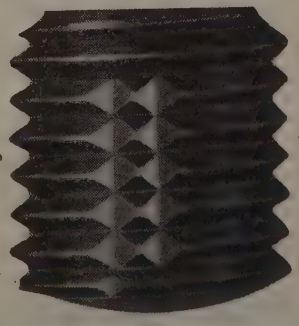
THIS IS THE BOLT THAT ONE MAN
TIGHTENS BETTER THAN TWO
— AND MORE EXACTLY.
ITS CORRECT LOADING IS AUTOMATIC;
ITS PERFORMANCE IS CERTAIN:
GKN GIVE IT CONTROLLED QUALITY.

GKN TORSHEAR

Patents applied for.

HIGH STRENGTH FRICTION GRIP BOLTING

MAKES CORRECT BOLT-LOADING AUTOMATICALLY CERTAIN



Inspection with TORSHEAR is reduced to seeing that this extension has sheared.

For details of High Strength Bolting technique including Torshear—get in touch with

GKN Guest Keen & Nettlefolds (Midlands) Ltd., Bolt & Nut Division: Atlas Works, Darlaston, S. Staffs.
TELEPHONE: JAMES BRIDGE 3100 (10 LINES) TELEX: 33-228

D/T1182

you can't drop a spanner in the works

with this flooring

SAFETREAD

WELDED STEEL FLOORING

Engineers everywhere are aware of the unique design and construction of 'Safetread' flooring—its construction has gained universal appeal as it provides the greatest possible strength and rigidity with a minimum use of steel, thus enabling valuable economies to be effected in supporting members.

With Safetread's welded construction, nothing can work loose or cause chattering through vibration—its design enables maximum light and air penetration and yet the danger of tools or other similar objects falling through is reduced to an absolute minimum.

Write today for a catalogue of Safetread "tailor-made" flooring—amply illustrated, it contains deflection tables, safe-load tables, and a wealth of useful information for the man with a flooring problem.

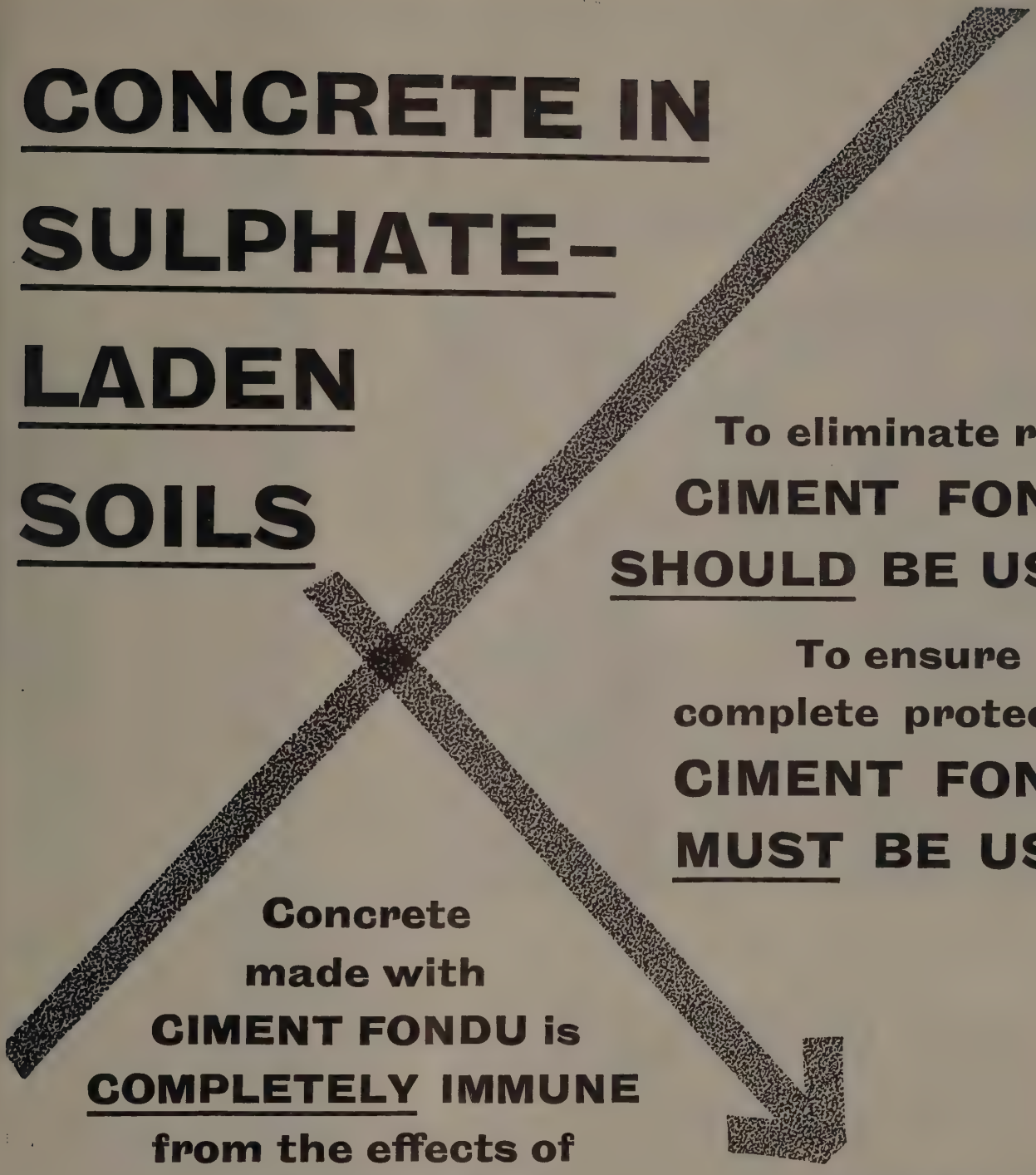
ALLAN KENNEDY & CO · LTD

MARITIME STREET · STOCKTON-ON-TEES

Telephones: STOCKTON 65464 (4 lines) · Grams: 'GRATING' STOCKTON-ON-TEES

London Office: ABFORD HOUSE WILTON ROAD LONDON S.W.1 · Tel: VICtoria 2539

CONCRETE IN SULPHATE-LADEN SOILS



To eliminate risk
CIMENT FONDU
SHOULD BE USED

To ensure
complete protection
CIMENT FONDU
MUST BE USED

Concrete
made with
CIMENT FONDU is
COMPLETELY IMMUNE
from the effects of
SULPHATES
in any concentration

Concrete made with Ciment Fondu provides an additional margin of safety! It is also resistant to attack by dilute acids often prevalent in sulphate-bearing clays, made-up ground and many industrial effluents.

CIMENT FONDU
Regd Trade Mark
ALUMINOUS CEMENT

★ *Send for leaflet TSS-16 "The Influence of Mineral Sulphates on the Permanence of Concrete Structures."*

LAFARGE ALUMINOUS CEMENT COMPANY LIMITED, 73, BROOK STREET, LONDON, W.1. Telephone: MAYfair 8546

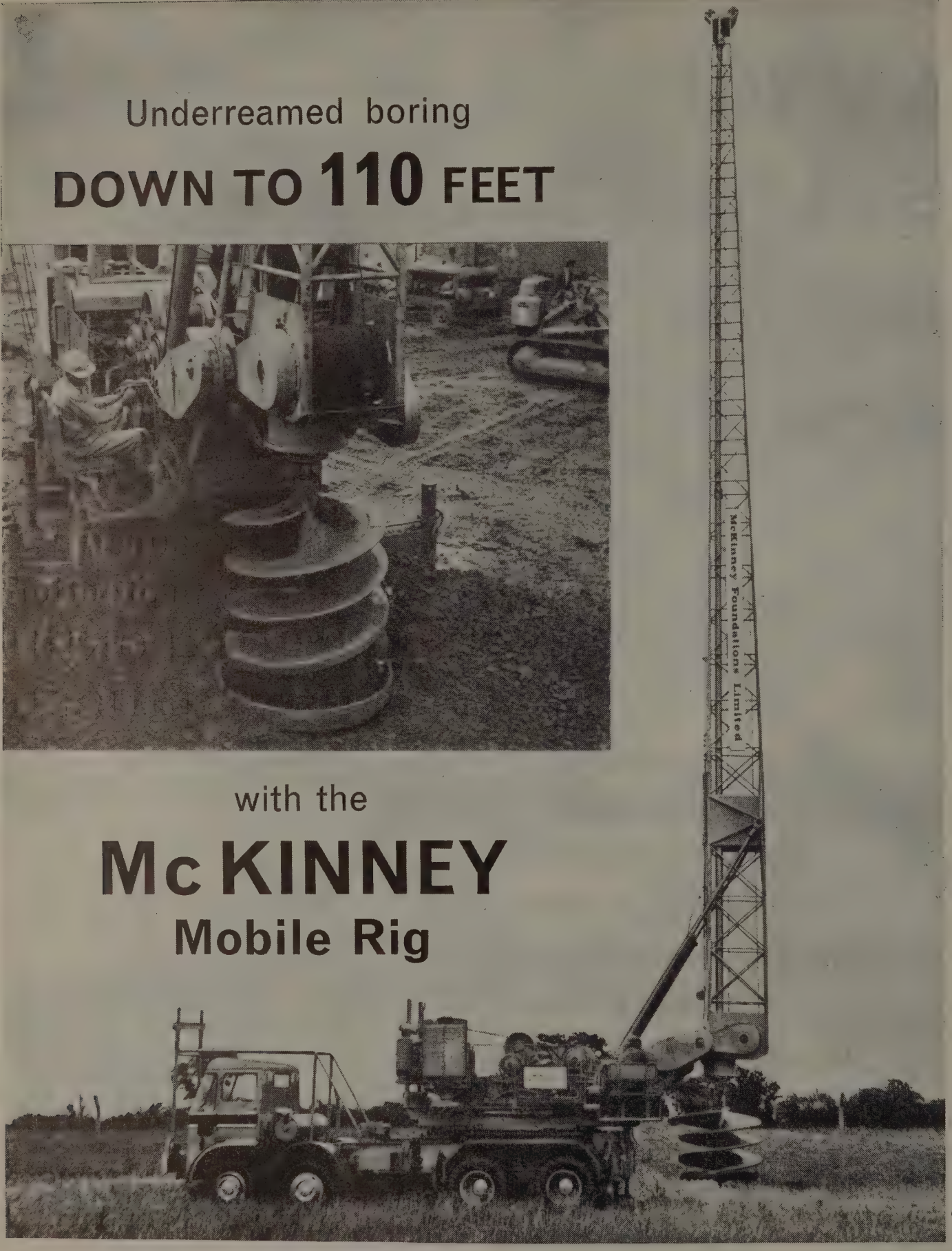
AP/67

Underreamed boring

DOWN TO 110 FEET

with the

Mc KINNEY
Mobile Rig



If you would like further details, please write to:

A LAING COMPANY

McKINNEY FOUNDATIONS LIMITED

Manor Way, Boreham Wood, Hertfordshire. Telephone: Elstree 2854

VOL. XXXVIII. No. 3. MARCH, 1960

THE STRUCTURAL ENGINEER

THE JOURNAL OF THE INSTITUTION OF STRUCTURAL ENGINEERS

Founded 1908. *Incorporated by Royal Charter* 1934.

11 UPPER BELGRAVE STREET, LONDON, S.W.1. Sloane 7128/9.

President:
L. E. KENT, B.Sc.(Eng.), M.I.Struct.E., M.I.C.E.

Secretary of the Institution:
Major R. F. Maitland, O.B.E., M.I.Struct.E., M.Soc.C.E.(France).

Assistant Secretary:
Lt.-Col. N. M. Hay, M.B.E.

CONTENTS

PAGE

NEW DEVELOPMENTS IN STRUCTURAL ANALYSIS AND DESIGN BY MEANS OF THE ELECTRONIC COMPUTER:-

(1) APPLICATION OF AN ELECTRONIC DIGITAL COMPUTER TO STRUCTURAL STEEL DESIGN 75
by L. Morgan

(2) THE ANALYSIS OF GRID FRAMEWORKS AND FLOOR SYSTEMS BY THE ELECTRONIC COMPUTER 79
by E. Lightfoot, M.Sc.(Eng.), Ph.D., M.I.Struct.E., A.M.I.C.E., (Delegate Member of Council) and F. Sawko, B.Sc.

(3) ELASTIC CRITICAL LOADS OF MULTI-BAY PITCHED ROOF PORTAL FRAMES WITH RIGID EXTERNAL STANCHIONS 88
by D. M. Brotton, B.Sc., Ph.D., A.M.I.Struct.E.
The Structural Engineer, March, 1960

RESEARCH FOR THE CONCRETE INDUSTRY 100
The Work of the Research Organisation of the Cement and Concrete Association
by A. R. Collins, M.B.E., D.Sc., M.I.Struct.E., M.I.C.E. (Member of Council)
The Structural Engineer, March, 1960

BOOK REVIEWS 115, 121, 122

INSTITUTION NOTICES AND PROCEEDINGS 116

All Editorial communications should be addressed to The Editor, The Structural Engineer, 11, Upper Belgrave Street, S.W.1. All MSS. should be typewritten and algebraic signs and formulae be indicated distinctly.

The Institution of Structural Engineers, whilst being at all times desirous of receiving communications from members and others, does not accept any responsibility for the opinions expressed by any individual Authors or Speakers.

Annual Subscription Rate to the Journal £3 3s. 0d. post free.

Printed and Published for the Institution by JOHN MORRIS PUBLICITY LTD., Publicity House, 41 Streatham Hill, London, S.W.2, to whom all communications regarding advertisements should be addressed.

FOR COMPLETION ON TIME

LAING LONDON

LAING CARLISLE

LAING NEWCASTLE

LAING GLASGOW

LAING BIRMINGHAM

LAING BRISTOL

The services of the Laing Organisation are available throughout Great Britain

JOHN LAING AND SON LIMITED
BUILDING AND CIVIL ENGINEERING CONTRACTORS

NEW DEVELOPMENTS IN STRUCTURAL ANALYSIS AND DESIGN BY MEANS OF THE ELECTRONIC COMPUTER

Three Papers to be read before the Institution of Structural Engineers, at 11 Upper Belgrave Street, London, S.W.1, on Thursday, 10th March, 1960, at 6 p.m.

(1) Application of an Electronic Digital Computer to Structural Steel Design

by L. Morgan

The United Steel Company's Pegasus Computer was installed in Sheffield in February, 1958, and one of the first major tasks assigned to the programming staff was in the field of structural steel design. This particular application of the computer had been suggested by the United Steel Structural Company with a view to employing the machine on their problems.

Whilst the programmers were mathematicians of the first order and knew Pegasus inside out, they did not know anything about the design of the steel structures. This of course was only to be expected, as was the fact that the Structural Company's design staff knew nothing about electronic digital computers.

At first it was thought that as neither party knew the other's job the production of a good and useful programme would be difficult. As events have proved, this was a pessimistic view, and in many ways has turned out to be a blessing. It resulted in far more questions being asked by the programmers in order to get the feel of their problem, and this was reflected in the programme in that the Structural Company got what they wanted and not what someone else thought they wanted. The common ground between the parties was mathematics, and if the Structural Company could express their requirements in a logical sequence in the form of equations, the programmers' job would be made less difficult.

In six months the team produced a prototype programme that could design a grid of simply supported floor beams, giving the required section to satisfy bending stress, including the effects of instability; web stresses with respect to shear, buckling, and crushing; and deflection criteria. But this will be considered in more detail later in the paper.

It may be asked why so simple an operation should be considered for the computer. Did it warrant all the development time necessary to programme? The arguments in favour were firstly that it would have a wide range of usability, for most structures have a floor or a flat roof. It must be realised that in order to be economic a programme must be used to the full. Secondly, a certain amount of data was already in existence in a form that would be directly useful to the programmers in their task. The monotony of wading through an endless assortment of simple beams on the part of a designer was appreciated by the management; surely the drudgery of this mechanical task was best left to a machine which would not wilt at the prospect of embarking on a timeless cruise o'er an endless sea. The fact that Pegasus was a tool for solving complex indeterminate structures had not gone unnoticed; problems that would take a designer days to solve, and perhaps even then only by making doubtful assumptions for simplification, all of which the Computer would take in its stride. But this was ground on which others were already engaged, the Structural Company chose virgin soil in which to dig, and have therefore produced something they believe to be unique.

Once the target had been set it was attacked from two angles simultaneously, for the problem divided itself naturally into two parts. On the one hand was the organisational part which was required to convert a drawing into computer language, allocate loads to beams and to decide the order of computation. On the other was the design part, which would then take over, stress the beams and produce the most economical sections for the job.

For the benefit of those who have had no dealings at all with an electronic computer, perhaps a few words of explanation of its function would be appropriate at this juncture, the better to understand the problems that follow. The main point is that this machine can work out anything, provided someone will tell it exactly what to do. Nothing can be left to common sense, because it has none. It has however, a terrific memory, for one only has to tell it once, and thereafter it will treat similar problems with different data in the same way. Memory here refers to the programme, and not to an internal mechanism. The programme then, is a length of paper tape, on which is punched a set of instructions to the computer on how to handle a specific job, for example, how to design a floor. Run in with this programme tape is a data tape, giving the figures for the particular floor that one is interested in at the time. It follows then that the programme tape is used repeatedly, whereas the data tape is only used once, and these tapes constitute the input. The output is also by paper tape, the programme having told the machine what answers are required. The output punch is therefore automatic. However, the output tape is still in computer language, that is to say, a series of holes, up to five in a row across the width. A skilled programmer could probably read this directly, but it is simpler to put it through a tape reader which controls a teleprinter, and this transcribes it into English. By this time the programme is probably rolled up and waiting for the next job, but its influence went right through to the end. It had to tell the computer what instructions to punch out to control the teleprinter, such things as space, figure shift and line feed. If the above account shows up the type detail that is necessary in preparing a programme it has served its purpose.

The organisational part is based on a grid system of co-ordinates. These are numbered, not necessarily consecutively, right through the job. A co-ordinate must be placed through each point of interest, for example, point of support, or change in direction of

an area boundary. It is then possible to describe a floor layout drawing in terms of the co-ordinates (x, y). The first data required is a list of these co-ordinates with their distance from an origin such that there are no negative quantities. Subsequently, no dimensions in terms of feet and inches are required, the computer works out its own from this reference list.

A definition of the areas involved is the next information required. By quoting the co-ordinates in sequence around the perimeter, and prefixing each by a number, the shape and the loading can be described. This is done for each superficial load ; should there be an opening such as a stair or light well, the loading is given as zero. If the prefix number referred to above be an integer, the computer understands the units to be in lb. per square foot ; if it is a decimal number, tons per square foot are inferred. The latter units are hardly likely to occur, but the principle holds good when dealing with linear and point loads ; which are the next data required. The former requires co-ordinates to be defined at each end, and at any intermediate point where a change of direction occurs. The point load of course requires only one set of co-ordinates.

The loading is followed by the points of support such as columns, and the line supports, such as retaining walls, and then the beams. These are prefixed with three different warning characters to define them, whether they are plain, cased, or "dummy." The need to differentiate between the first two is obvious but the latter will require some explanation. A " dummy " beam is not designed, consequently it needs no supports, and is similar to a line support in that it will define an area and share the floor load with the nearest beam.

The necessity for " dummy " beams arises from the fact that it is not always possible to design the whole floor at once ; the storage capacity of the computer may be insufficient. In these cases the area is partitioned into sub areas, and " dummy " beams introduced on the boundaries where the data for a design is incomplete in the portion under consideration.

Other features of the input data are sequences for holes in flanges and transferred reactions. Where co-ordinates are given under the former, Pegasus will apply the net modulus of the beam section when checking bending stress ; either two or four holes out of the cross section can be catered for. A transferred reaction is used when partitioning of the area is necessary ; it will be the end reaction from a beam computed in a previous sub-area, and will therefore be unknown at the time of writing the data. Further, the warning character differentiates it from a point load, in that the computer recognizes the fact that there is a beam at this point which will provide lateral support.

This constitutes all the input data for the programme, and will give some idea of its scope. All that is necessary to add is that all beams must be pin-ended with top flanges flush and parallel to one of the reference axes. Skew beams can be dealt with in the design half of the programme but not in the first, that is to say a superficial load cannot be allocated to it. If the input can be adjusted to suit, that is, a linear load placed on the beam and the adjoining area made zero, the beam will be designed. A similar dodge is employed if the floor spans the wrong way. One of the first jobs the computer has to do is to convert the superficial loads into linear loads. This it does by searching in turn the rectangles formed by the beams, summing the total load contained therein and apportioning half to each beam forming the long side, that is spanning the short way. If the rectangle happens to be a square it spans parallel to the Y axis, and if for some reason the floor is to span the long dimension of the rectangle the device mentioned above may be employed. It should be mentioned that it is not necessary for the boundary between different loading areas to coincide with beams, in other words, the rectangles formed by the floor beams can contain more than one loading per square foot. In this case the appropriate distribution to supporting beams will be made and not half-and-half as previously mentioned.

All loads are now allocated to beams including a number of unknown ones from supported beams, and the design portion of the programme comes into play. The grid of beams is searched until the first one is found having only two unknown loads, these must be its end reactions, and it is therefore capable of solution. After design, these figures are transferred to the supporting beams thus reducing the number of unknowns in these cases. The equipment then proceeds to search for the next beam having only two unknowns, which it calculates and so on, until it completes the whole grid. Then it returns to the beginning and runs through again, and again, until all beams have been designed.

In the design of a simply supported beam the equipment makes the same checks and arrives at the same answers as would a designer, but not necessarily by the same methods. What is simple to man is not necessarily simple to a programme, and what is tedious to a designer is no trouble to a computer. With experience, a designer can short cut many of the checks, knowing by inspection and experience that they cannot control the beam size. But ask him why he knows this, ask him for a set of rules when a check is worth making and when it is not, and he will probably find this harder than making the check—and so does Pegasus. Consequently, every check is applied to every beam. If a human being were to accept this policy the production time would increase enormously, but the speed of a computer is such that it can do all the checks before its intelligent competitor has written the title. This sometimes gives some amusing answers, for instance the deflection of a short tie, with no load other than its own weight may be given as one millionth of the span, and its stress as a fraction of a ton per square inch.

When a beam has been selected from the list as being capable of design, the end reactions are found, also the maximum bending moment existing within each length between points of lateral support. The bending moment is then found at any position where a hole in the flange has been defined, and the highest of each group is converted to a required modulus, gross and net respectively, for a stress of 10 tons per in^2. It may be wondered why all these moments are calculated, and not just the maximum of each on the beam. This is because they are used for checking the stability. B.S.S. 449 : 1948 states that the permissible bending stress shall be 10 T/in^2 or $\frac{1000\,rK}{l}$ whichever shall be the less. This parameter is equated to $\frac{M}{Z}$ and the equation transposed to the form :—

$$rKZ = \frac{Ml}{1000}$$

The left hand side is made up of sectional constants, and has been calculated for every section rolled. The right hand side is computed by Pegasus for each length of the beam between lateral supports, and the highest of these is noted.

After this the maximum deflection on the beam is found and is converted to a required Inertia for any previously established maximum deflection so we now have a list of requirements and wish to find the lightest

beam which will satisfy all of them. This is done by listing the sections available in order of weight, and feeding it in as part of the programme in the form of a table giving all the constants in which we are interested. With regard to the web, the table gives against each section the maximum load that it will take in shear, and the maximum it will sustain without web buckling or crushing, excluding the effect of the thickness of flange plates. These maxima are compared in the equipment against gross end reaction.

Up to date nothing has been said about the self weight of the beam, and in this lies perhaps the best indication of the fantastic speed at which the computer works, and the difference of approach between man and machine. All that has been said so far is applied to the lightest beam on the list, that is to say that the appropriate weight of this beam, be it cased or plain is added to the loading before starting to find the end reactions. The programme contains a formula to work out the weight of casing where applicable. The beam requirements are then checked against the table of constants of the lightest beam to discover if it has sufficient modulus, gross and nett; suitable inertia against deflection; and web strength for shear, and so on. If the beam fails on any of these counts, the whole process is repeated for the next beam on the list, and so on until one is found that does not. The programme then checks the stability parameter rKZ, and the web buckling and crushing figures. If these are not satisfactory, the fact is noted, and the search continues up the list until all conditions are satisfied, and a note made of the beam that will do this. If the top of the list is reached without finding such a beam, this fact is noted also. Having now got one and possibly two beams for the job, calculations are made of the maximum stresses and the points at which they occur, also the maximum deflection in terms of a ratio of the span. This completes the computation, and the output punch begins to clatter. The time taken from starting with the lightest beam, trying every beam in the British Standard range, and discovering that the heaviest is unsuitable, averages ten seconds!

It may have been noticed that reference was constantly made to the lightest or heaviest beam on the list without quoting any specific section. This was done deliberately because the list can be varied at will. On any particular run the facility exists for deleting any entry, thereby precluding a section from selection which is not, or will not be available. It should also be mentioned that the company's range of Castella beams are listed, and can be chosen if desired. They will automatically be given as an alternative, if deflection has controlled the design of the plain section.

Now to the answers. These are punched out for each beam immediately they have been computed, and before the computer tackles the next beam. This means that the tape reader and teleprinter can be brought into play before the whole problem has been solved, with consequent reductions in overall time. Equally important though is the fact that the registers containing these answers will be required for succeeding beams. The output is produced under standard headings although variations on the theme are produced dependent upon observations made by the computer during its excursion through the beam list. Examples of these are set out as follows :—

Beam No. 16

Position	53·19 *N*
Length	14—8
Reactions	12·09 13·12
Section	15 × 5
Max. Stress	* 9·4 at 7—4·75 and 3·69 at 13—5
Deflection	1/564
Stability	(T) 94·5

Beam No. 16

Position	53·19 *N*
Length	14—8
Reactions	12·11 13·14
Section	14 × 6
Max. Stress	8·5 at 7—4·75 and 3·35 at 13—5
Deflection	1/582
Stability	* 94·6

Beam No. 13

Position	50·13 *N*
Length	24—4
Reactions	22·82 29·24
Section	(Compound) 1·03

$Z = 239{\cdot}29$ at 13—7·25 and * 239·29 at 13—7·25
$I = 1229{\cdot}4$
$RKZ = 308{\cdot}1$

It will be noted that if the beam fails on stability or web buckling it is printed out nevertheless, with warning characters to indicate the insufficiency. This is because it may be possible for the designer to overcome these discrepancies without increasing the beam size. If this is not possible then he has the heavier alternative.

This is apparent from the first two examples given which are for the same beam. The warning character (T) after "Stability" signifies that ties are required if this section is to be used, and the asterisk denotes which aspect was critical in choosing the section size.

Note that the asterisk has moved from stress in the first case to stability in the second. Note also the slight increase in end reactions and stability requirement due to the heavier section. The first stress given is the maximum bending moment divided by the gross modulus, the second is the maximum stress using net modulus, at a position where a hole has been drilled in the flange. In the third example there happened to be a drilling at the position of maximum bending moment so the figures for required Z are the same but in the first case it is referred to gross modulus and in the second to net modulus. The asterisk appears with the net value because this will obviously govern. The figure given after the stress is the distance in feet and inches from datum end, defined below.

The programme does not include data for compound beam design. Consequently, the best it can do is to print out the requirements from which a designer can readily choose such a beam. The figures given will include the self weight of the last beam on the list, the actual weight so included is written after the word (Compound).

So the first alternative for beam 16 has one end at co-ordinates $x = 53$ $y = 19$, from which it runs north (y direction) for a distance of fourteen feet eight inches. The reactions of the 15 × 5 joist selected, are 12·09 tons at the datum end (53·19), and at 13·12 tons at the other. The maximum stress, which governed the size chosen, is 9·4 T/in^2 and occurs at 7 ft. 4$\frac{3}{4}$ in. from the datum. The stress in the net section where a drilling occurs at 13 ft. 5 in. from the datum, is 3·69 T/in^2. The maximum deflection is one five hundred and sixty fourth of the span, and the beam requires an RKZ value of 94·5—which it cannot muster, hence the (T).

In beam No. 13, the third example, stress was the controlling condition at the time the computer ran out of sections. All the results it gives include the self weight of 1·03 tons which in this case was for 24 × 7$\frac{1}{2}$ in.

joist. This means that the designer would have to allow for the weight of the flange plates of this compound.

At the time of writing the programme has been operational for six months and has been used in many jobs. Experience has shown that the bigger the job in size and complexity the more useful it is. If the job is large, but can be reduced to say a dozen different beams due to repetition it is not worth the time spent in preparing the data, consequently something should be said about overall time, the yardstick of comparison with manual methods. By far the longest period is that spent in preparing the data. The ratio of this time, to the computing and print out time is in the order of fifteen to one. Four hours in all for a sub-area containing forty beams would be the total design time, with teleprinter links and no waiting. It is left to the reader to assess whether he could match this rate—and keep it up ; further, how long it would take him to do it a second time when the loading had been altered, for the computer would take half an hour ; it would not take long to amend the input data.

Now what of accuracy, and possibility of error ? The former far surpasses that obtained from a slide-rule, which is sufficient for the tolerances encountered in structural engineering. As to the latter, these do arise, and upon investigation it is found that the computer has given the right answer to the wrong question ; in other words the data was wrong. It is essential that all input data be checked thoroughly, it does not pay to rush it. If the punctuation is wrong, either an error or a stoppage will occur, and this may take a lot of time to find, but this is common to all computer programmes. On the odd occasion when it does make a mistake, it is generally of such magnitude that it is obvious. During the period that the Author has been associated with Pegasus, he has come across only one computer error, which was really an error by the output teleprinter. Somehow it had missed a letter shift, and instead of printing out " Max. Stress " it produced a series of strokes, asterisks, equals etc., in fact it looked as though it had sworn!

Mention must also be made of the fact that United Steel Structural Company is also operating to advantage a programme for plane frames. The analytical method employed was originated by Dr. R. K. Livesley (now at Cambridge University) for a programme for the Manchester Mk.1 Computer. The present programme was devised by M. Rooney in 1958, and caters for an elastic analysis of two dimensional, rigid jointed frames. Over a period of about six months some three dozen jobs have been completed with its aid. Of these some have had up to twelve alternative loading cases, and other variables of the data. This programme has made possible a degree of finesse that would be impractical by any other method.

One particular adaptation of this programme is perhaps worth special mention, as it is possible that it has never been used before for such a purpose. A piece of machinery contained a rotating shaft, some 22 feet long, mounted on four journal bearings spaced out along this length. The base of the machine was supported on two lines of twin fifteen-inch channels, running over the top flanges of four floor beams normal to the shaft and the channels, but not under the bearings. Two of the floor beams, numbers one and three in fact, had a column at each end, while numbers two and four were supported on columns at one end and by separate beams at the other, and thence to a column. It was essential for the correct functioning of the machine that any condition of floor loading should not result in an out-of-alignment of the bearings by more than 1/16 in. So the problem resolved itself into two continuous beams over sinking supports, with no symmetry in either the loading or the beam arrangement.

Having put the problem, the reader may now be tempted to ask what connection it has with a plane frame, and the answer is that the beam system was arranged to represent one. The beams were suspended one beneath the other and rotated into the same plane. Beam connections were represented by vertical members having minimum length, maximum area, and zero inertia. In terms of the programme the system produced thirty-four joints, thirty-two members and twenty zero deflections. This of course required partitioning, but it produced the answer.

Two questions were recently put with regard to the floor programme. The first was, " Is it possible for the machine, using this programme, to disclose a need for a revised range of British Standard Beams ? " The other was " Is the advent of computers likely to make designers redundant? " The short answer to both is " No, because computers cannot think." But to the first, one might have said :— " What you are suggesting is tantamount to the computer suddenly stopping in its tracks and punching out :— 'On many occasions the requirements have just been too much for a 22 in. × 7in. and I have had to throw away 20 lb/ft. in selecting a 24 in. × 7½ in. joist. I think there is a case for an intermediate size ? ' When we have a computer capable of this, the designer can start looking for a job."

Acknowledgments

In the production of the floor programme, and research into the scope of the frame programme most of the load has fallen on the Operational Research and Cybernetics Department of the United Steel Companies Limited. The Author wishes to record his thanks to Mr. D. G. Owen, Mr. M. B. Card, and Mr. W. M. P. Hutson of that department for much painstaking work in carrying out an extensive and detailed operation. They have produced something, which although not fully developed at the time of writing, has nevertheless saved many man hours already, in terms of design time. Their work goes on, expanding and developing the latent talents of the " new boy " on the design staff.

(2) The Analysis of Grid Frameworks and Floor Systems by the Electronic Computer

By

E. Lightfoot, M.Sc.(Eng.), Ph.D., M.I.Struct.E., A.M.I.C.E. (Delegate Member of Council),

and F. Sawko, B.Sc.

1. Introduction

The generalised slope-deflection method of structural analysis is now quite well-known and is particularly suitable for the electronic computer solution of rigid-jointed frameworks. It was used for the analysis of *plane* frameworks by Livesley,[1,2] who went on to develop his basic computer programme to include for automatic design and elastic instability[3]. There is no theoretical difficulty in extending the method for the elastic analysis of any *space* structure, with the following variations allowed in the members, if applicable :—

(i) variable sections,
(ii) curved or bent centre-lines,
(iii) rigid, pinned or elastically-restrained connections.

It is also possible to include for the effects of :—

(iv) shearing, twisting, axial and bending deformations,
(v) elastic supports along the lengths of members,
(vi) force, moment and torque loadings,
(vii) settlements and temperature changes.

Before all these various effects can be included, however, it will be necessary to establish the relevant stiffness and restraint factors for the members, with items (i) to (v) allowed for; it will also be necessary to obtain the fixed-end forces, moments and torques occurring at the ends of the members for any of the loading effects (vi) and (vii), again allowing for items (i) to (v). It will then be possible to determine the forces and moments (including torques) acting at the ends of the members by means of the generalised slope-deflection method, utilizing the computer. Moments (and torques) along the lengths of members may need to be determined by further computer calculations if certain non-linear effects are appreciable, e.g. those due to high axial loadings, and to continuous elastic reactions acting along the lengths of the members.

The production of master programmes for the electronic computer is a laborious task and a completely general analysis, on the lines suggested, has not yet been achieved. Livesley's programme for plane frameworks was, however, re-written for the Ferranti Pegasus computer by Rooney[4] during 1958, and is now available for general usage. Rooney has proceeded to write a further programme which will analyse a plane framework of any size, without any restrictions to the number of members, joints and boundary restraints, provided the framework can be divided into a number of linearly-connected parts with less than about ten common joints at each division. This is a considerable development on his original " single " plane frameworks programme, and is made possible by means of a partitioning treatment, like that previously used by Livesley. The storage capacity of an electronic computer restricts the size of the problems it can manage in a single manipulation, even when auxiliary storage facilities, such as magnetic tape, are available; this partitioning technique allows a computer to solve problems by parts.

The Authors conceived the idea, late in 1958, of adapting Rooney's Pegasus programme so that it would solve *grid* frameworks instead of plane frameworks. This alteration was soon achieved, but was only possible (as an *alteration*), because all the essential information about the internal planning and storage of the original programme was, very generously, made available to them. Both the plane and the grid framework are reduced forms of the space framework, so it seems worthwhile including here the generalised slope-deflection method in a completely general form, which can be used with any of the variations mentioned earlier.

There is, clearly, much work required before *any* framed structure can be analysed by the computer, with all the important effects included. This new grid frameworks programme is, however, quite a substantial development since it applies to a type of structure which has previously proved unsuitable for moment distribution or any other really easy methods. Analysis has been shown to be possible by means of Fourier series and other expansions, and an influence coefficients method based on deflections, only, has also been applied. In the absence of any direct analytical method suitable for the design office, these various methods have been used for the preparation of distribution coefficients, to allow for load sharing between adjacent members. It appears now that such coefficients might be prepared more easily and accurately by this new method, if such " potted " results are required for various types of floor system. The master programme can still, of course, be used for such structures where no distribution coefficients are already available.

Since the original master tape was transcribed for single grid frameworks[5], the Authors have produced the counter-part of Rooney's partitioned frame programme; again with his ready assistance. This programme has been further amended to utilize the magnetic tape auxiliary storage, thus reducing the machine time by about a third. It has also been found that this basic grid frameworks solution can be used for the analysis of several related types of structure, for example, for girders curved in plan, for interconnected beams and slabs, for slabs alone, for tanks and bunkers square in plan. This paper is presented to demonstrate some of these varied applications, and

to encourage the practising engineer to utilize this computer method.

2. Outline of the Generalised Slope-Deflection Method

Consider any particular member 12 for deformations at the end 1, with the end 2 completely fixed. If rectilinear axes p, q, r are chosen at the end 1, with the axis p lying along 12 for convenience, and if rotations about the p, q and r axes are defined by α, β, γ, then the set of forces and moments which must act at the end 1 for unit deformation in the p direction (say) may be written s_{pp}, s_{qp}, s_{rp}, $s_{\gamma p}$ $s_{\beta p}$, $s_{\gamma p}$; similarly for unit deformation of the end 1 in any of the other five directions q, r, α, β, γ. Thus, for deformations p, q, r, α, β, γ, at the end 1, the forces P'_{12}, Q'_{12} and R'_{12} and the moments A'_{12}, B'_{12}, and C'_{12} required to act there are given in matrix form as :

$$\begin{bmatrix} P' \\ Q' \\ R' \\ A' \\ B' \\ C' \end{bmatrix}_{12} = \begin{bmatrix} s_{pp} & s_{pq} & s_{pr} & s_{p\alpha} & s_{p\beta} & s_{p\gamma} \\ s_{qp} & s_{qq} & s_{qr} & s_{q\alpha} & s_{q\beta} & s_{q\gamma} \\ s_{rp} & s_{rq} & s_{rr} & s_{r\alpha} & s_{r\beta} & s_{r\gamma} \\ s_{\alpha p} & s_{\alpha q} & s_{\alpha r} & s_{\alpha\alpha} & s_{\alpha\beta} & s_{\alpha\gamma} \\ s_{\beta p} & s_{\beta q} & s_{\beta r} & s_{\beta\alpha} & s_{\beta\beta} & s_{\beta\gamma} \\ s_{\gamma p} & s_{\gamma q} & s_{\gamma r} & s_{\gamma\alpha} & s_{\gamma\beta} & s_{\gamma\gamma} \end{bmatrix}_{12} \begin{bmatrix} p \\ q \\ r \\ \alpha \\ \beta \\ \gamma \end{bmatrix}_1 \quad \cdots \quad (1)$$

This equation may be simply written as :

$$[F']_{12} = [S]_{12}\ [D]_1 \text{ (so defining terms)} \quad . \quad (2)$$

The forces and moments acting at the end 2 are related to those at the end 1 by the simple conditions of static equilibrium ; they can be written in a similar form to that in equation (2) as :

$$[F']_{21} = [R]_{21}\ [D]_1 \quad \cdots \quad (3)$$

Here $[R]$ represents a matrix of coefficients which are easily related to the *stiffness* factors shown in the 6×6 matrix of equation (1) ; $[S]$ is called a " stiffness " matrix and $[R]$ a " restraint " matrix.

If the member 12 is kept fixed at the end 1 while various displacements $[D]_2$ are applied at the other end, then

$$[F'']_{12} = [R]_{12}\ [D]_2 \quad \cdots \quad (4)$$

by the same process.

Also, suppose the member 12 has various forces and moments applied along its length, and that these are balanced by fixed-end forces and moments P^F_{12}, Q^F_{12}, R^F_{12}, A^F_{12}, B^F_{12}, C^F_{12} at the end 1 (and similarly at the end 2). Then, for any permitted set of displacements $[D]_1$ and $[D]_2$ at the two ends of the member,

$$\begin{aligned}[F]_{12} &= [F']_{12} + [F'']_{12} + [F^F]_{12} \\ &= [S]_{12}\ [D]_1 + [R]_{12}\ [D]_2 + [F^F]_{12} \quad (5)\end{aligned}$$

This equation is the basic generalised slope-deflection equation for the member 12 in space, referred to axes p, q, r. It may be written in terms of equivalent sets of forces and moments, stiffness and restraint factors, and displacements, all referred to separate x, y, z axes. Thus, if :

$$\begin{aligned}&[F]_{xyz} = [T] \cdot [F]_{pqr}, \\ &\text{i.e.} \quad [F]_{pqr} = [T]^{-1}\ [F]_{xyz} \quad \cdots \quad (6) \\ &[D]_{xyz} = [T] \cdot [D]_{pqr}, \\ &\text{i.e.} \quad [D]_{pqr} = [T]^{-1}\ [D]_{xyz}\end{aligned}$$

where $[T]$ is the relevant *transposition* matrix, then, by substitution in equation (2) it is seen that :

$$\begin{aligned}&[T]^{-1}\ [F]_{xyz} = [S]_{pqr}\ [T]^{-1}\ [D]_{xyz} \quad \cdot \quad (7) \\ &\text{i.e.} \quad [F]_{xyz} = [T]\ [S]_{pqr}\ [T]^{-1}\ [D]_{xyz}\end{aligned}$$

Thus, by comparing this equation (2) with its counterpart in the x, y, z directions it is clear that

$$[S]_{xyz} = [T]\ [S]_{pqr}\ [T]^{-1} \quad \cdots \quad (8)$$

Similarly,

$$[R]_{xyz} = [T]\ [R]_{pqr}\ [T]^{-1} \quad \cdots \quad (9)$$

Thus these generalised slope-deflection equations referred to member axes p, q, r may be transposed to refer to any other set of orthogonal axes x, y, z and remain in a similar form. Now, using equation (5), with the values referring to a standard set of x, y, z axes, it is possible to write the conditions of static equilibrium at the joint 1 as :

$$[F^E]_1 = \Sigma\ [F]_{12}, \quad \cdots \quad (10)$$

where $[F^E]_1$ represents any applied forces and moments acting at the joint 1. Thus equation (5) may be written :

$$[F^E]_1 = (\Sigma[S]_{12})\ [D]_1 + \Sigma([R]_{12}[D]_2) + \Sigma[F^F]_{12} \cdot \quad (11)$$

This equation may be written more simply as :

$$[F]_1 = (\Sigma[S]_{12})\ [D]_1 + \Sigma([R]_{12} \cdot [D]_2), \quad \cdot \quad (12)$$

where $[F]_1 = [F^E]_1 - \Sigma[F^F]_{12}$, and equals the *equivalent* force and moment system acting at joint 1.

Considering now the equilibrium of an entire structure it is easily seen that upon addition of all the various joint equations a single, overall equation :

$$[F] = [S]\ [D] \quad \cdots \quad (13)$$

may be written for the structure, to relate the external equivalent forces and moments at the joints with the various joint displacements. Once this equation is established it can be solved for $[D]$; then equations (5) may be used to give the various $[F]_{xyz12}$ values, and thus the various $[F]_{pqr12}$ values. Thus the forces and moments acting at all the joints are completely determined.

For a *plane* framework, if the r, and z, axes are taken normal to the plane, only the forces P and Q, and the moments C, with their corresponding displacements p and q and γ, are operative in equations (1). The 6×6 member stiffness matrix reduces to a simple 3×3 matrix which, for a straight prismatic member, has a value :

$$\begin{bmatrix} s_{pp} & s_{pq} & s_{p\gamma} \\ s_{qp} & s_{qq} & s_{q\gamma} \\ s_{\gamma p} & s_{\gamma q} & s_{\gamma\gamma} \end{bmatrix} = \begin{bmatrix} +\frac{EA}{L} & 0 & 0 \\ 0 & +\frac{12EI}{L^3} & -\frac{6EI}{L^2} \\ 0 & -\frac{6EI}{L^2} & +\frac{4EI}{L} \end{bmatrix} \quad \cdots \quad (14)$$

Now, for a *grid* framework, only the forces R and the moments A and B, are operative in equations (1), (if, once again, the r, (and z) axes are taken normal to the plane of the structure).

Then :

$$\begin{bmatrix} s_{rr} & s_{r\alpha} & s_{r\beta} \\ s_{\alpha r} & s_{\alpha\alpha} & s_{\alpha\beta} \\ s_{\beta r} & s_{\beta\alpha} & s_{\beta\beta} \end{bmatrix} = \begin{bmatrix} +\frac{GJ}{L} & 0 & 0 \\ 0 & +\frac{4EI}{L} & +\frac{6EI}{L^2} \\ 0 & +\frac{6EI}{L^2} & +\frac{12EI}{L^3} \end{bmatrix} \quad . \quad . \quad . \quad (15)$$

In these equations L represents the length of a prismatic member, A its cross-sectional area, I its second moment of area about the neutral axis (assumed a principal axis), and J its *effective* polar second moment of area ; E is Young's modulus and G the modulus of rigidity. These member stiffness matrices show quite a few similarities ; and so do the restraint matrices (which are omitted for brevity). Also, since the moments A and B act about the p and q axes, they may be represented as vectors along those axes, and so the transposition matrix $[T]$ is the same in the two cases.

With this parallel appreciated it was possible to proceed to alter the internal structure of Rooney's master programmes for plane frameworks, and so to produce new master programmes for *grid* frameworks.

3. Similarities in the Plane and Grid Frameworks Programmes

Since the grid frameworks programme has been derived from the plane frameworks programme it possesses many similar features, e.g.

(i) the degree of redundancy is of no concern, and there is no need to consider it ;
(ii) the members may be orientated in any direction ;
(iii) only the equivalent external loading at the joints needs to be known ; the reactive forces and moments will be obtained in the result of the analysis ;
(iv) the effect of torsion is included automatically in the grid frameworks programme, just as the effect of axial elongations and contractions is allowed for in the original programme.

The procedures of tape preparation are almost identical in the two cases. Instead of linear restraints in the x and y directions, and rotational restraint about the perpendicular z axis, however, the new programme is concerned with rotational restraints about the x and y axes, and linear restraint in the z direction, (these are referred to by the numbers 1, 2 and 3). Another amendment is required : instead of the area, A, of a member the GJ/E value is inserted. As for a plane framework it is necessary to number the joints ; any system or sequence may be used, with consecutive numbers from 1.

The information required by the computer may be listed briefly as follows :

(a) the number of imposed zero displacements, the number of joints and the number of members ;
(b) the number of each support followed by the minus symbol and the number corresponding to the kind of restraint ;
(c) the equivalent external moments and forces applied at each joint, starting with joint 1, and giving the moments about the x and the y axes, and the force in the z direction, respectively ;
(d) the x and y coordinates of each joint, from joint 1 onwards ;
(e) the joint connection list, which also defines the members in order ;
(f) the value of Young's modulus for each member, in the order established ;
(g) the value of GJ/E for each member, and
(h) the value of I for each member.

This information should be preceded by a title, which will head the print-out of results. There are also several minor rules, standard for the Pegasus machine, which must always be obeyed in tape preparation.

The print-out of results is shown for the solution of Example 1, and is almost self-explanatory. It should perhaps be added that for a member 12, in plan, the torque and moments are respectively referred to a p axis along the member and, at the ends 1 and 2, to q axes which are positive in a direction 90 degrees anticlockwise from the direction 12 (that of p). Then for the member ($1 \rightarrow 2$) the torsion is given as positive if acting anticlockwise along the member 12 at the end 1, the moments at the ends 1 and 2 are positive if acting anticlockwise about their respective q axes, and the shear force is given as positive upwards at the end 1. Care is needed if the torques and moments at any joint are to be checked for equilibrium.

4. Applications

In perusing the technical literature on grid frameworks and floor systems the Authors have found few numerical examples amid innumerable descriptions of possible theoretical methods and approaches. This inherent difficulty might be expected, because the grid framework always deforms with a deflection and two rotations (of which one, at least, is appreciable), at each joint, whereas the plane framework, without sidesway, can be fairly accurately analysed on the assumption of joint rotations only (hence the moment distribution method).

It has also been found that existing published solutions are often in error, usually because some lengthy hand computing method has been employed. This electronic computer method gives correct results if the data for the problem is inserted correctly, and so it can be used with confidence. (Errors do occur, very infrequently, in electronic computing, but are usually of a random nature, so agreement with a repeat solution may be taken as an assurance of accuracy.) The master programme has been used to give solutions which check against accurate analytical results (e.g. for the circular bow girder), which confirms that errors have, in fact, been avoided. Actually, such checking is unnecessary, since the printed solution can itself be checked at each joint for static equilibrium and compatibility of deformation ; also, further overall checks can be applied as desired. However, most of the examples used below have also been solved by different independent methods, and it will be seen that the agreement is satisfactory.

This computer analysis automatically allows for the effect of torsion, but many of the methods previously proposed neglect either torsional restraints or deformations. For a grid framework composed of steel I-sections the effect of torsion may be quite small ; such a structure has been considered in Example 1. With reinforced concrete construction the effect of torsional strength may be considerable ; it is usually an important contribution to the strength of slabs. By allowing for it in the master programme it has been found possible to solve slabs exactly, in fact, the grid analogy for slab behaviour is almost as valid as the usual finite differences method based on

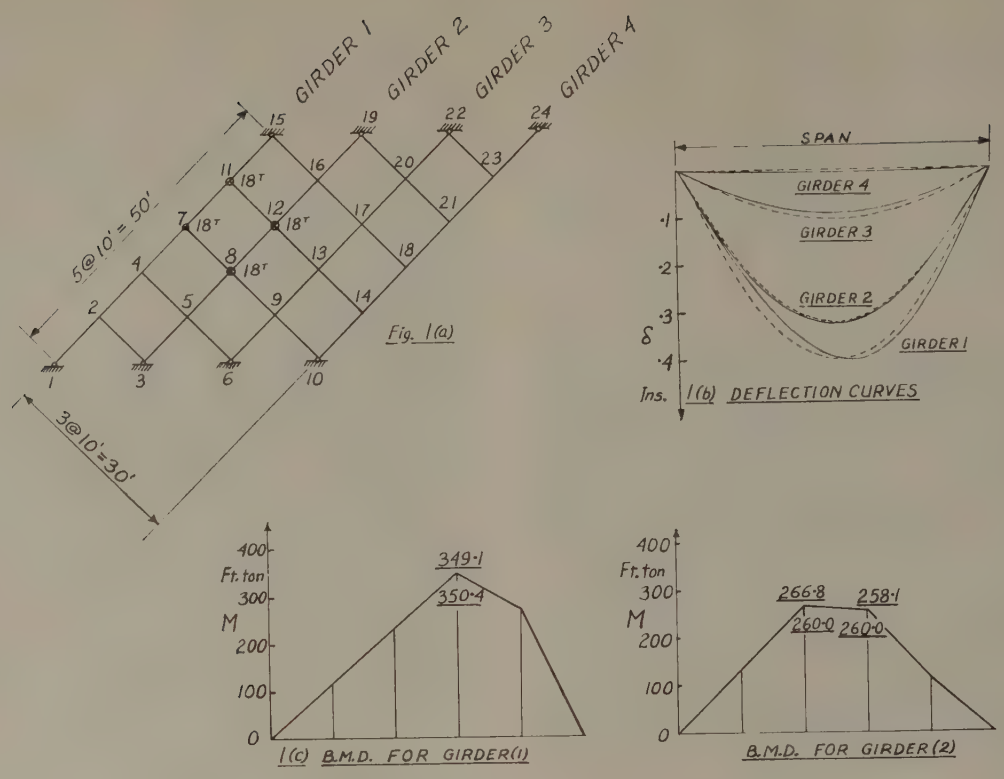


Fig. 1.—Bending moments for the skew bridge of Example 1.

the biharmonic equation for thin plates ; and in several ways it possesses outstanding advantages.

There are many unexplored structural and architectural possibilities for grid frameworks, and this new method of analysis will allow for the application of rational design to such cases. Diagrid floors can now be easily analysed, as demonstrated in Example 2 below. Other geometrical patterns could be exploited structurally ; this computer programme will solve any grid framework, no matter how the members vary in size and in their orientation. It is thought, however, that though the examples presented here cover quite a large field already, there might well be further interesting applications waiting to be discovered.

Example 1. *Gridwork for a skew bridge*

The structure to be analysed first is the grid framework for a skew bridge. The centre-line dimensions and the loading are shown in Fig. 1(a), where the main and transverse members have constant I values of 25,256 and 443 in.^{4} respectively, their J values being assumed zero. Though the loading is somewhat hypothetical any method of analysis to allow for it—such as this—could clearly be used further for the design of the structure against *any* stipulated traffic loading.

This problem has been taken from Hendry and Jaeger's recent textbook, " The Analysis of Grid Frameworks "[5]. In reporting the use of the single grid frameworks programme[6] the Authors previously used another problem from a paper by these two writers. In that case Hendry and Jaegers' experimental deflections were used as a confirmation of the correctness of the computer method ; now both their calculated deflections and bending moments are used for further confirmation ; this time for the correctness of the new partitioned grid frameworks programme. The original grid frameworks programme could not deal with this particular structure because it has 24 joints and the single grid frameworks programme cannot cope with more than 18

The deflections obtained for girders 1, 2, 3 and 4 are drawn to scale in Fig. 1(b) with full lines, the curves obtained by Hendry and Jaeger being shown dotted for comparison. Bending moment diagrams for girders 1 and 2 are shown in Fig. 1(c), some of the values obtained by Hendry and Jaeger being marked in brackets, since dotted lines would be indistinguishable. It will be observed how closely these results agree.

By way of interest the print-out of the computer values is shown in Tables 1 and 2, the joint numbers corresponding to those in Fig. 1(a). Actually, the deflection and then the force and moment values are printed out for each sub-frame in turn, but the deflections have been set out together in Table 1 and the forces and moments in Table 2. It should be mentioned that the origin for coordinates was taken as joint 1 with the line 1, 10 taken as the x axis, the y axis being at 90 degrees anti-clockwise from this. The rotations of the nodes under load are referred to these axes, but the torques and moments are referred to member axes.

Example 2. *Diagrid Floor Systems*

The diagrid floor shown in Fig. 2(a) covers an area of 60 ft. by 40 ft. and consists of beams 12 in. wide by 24 in. deep throughout. The value of Poisson's ratio μ has been taken as zero, though any reasonable value might have been used. The I and J values for each beam equal 13,824 and 9,497 in.^{4} respectively, the latter value being obtained from the expression $J = K_1 bt^3$, where $K_1 = 0.229$ for $t/b = \frac{1}{2}$, (t being the smaller and b the larger outside dimension). With

DEFLECTIONS INS. AND RADIANS

Joint No.	*X-Rotation*	*Y-Rotation*	*Vertical*
1	+0·00265310	+0·00000000	+0·00000000
2	+0·00241168	+0·00012066	−0·21493782
3	+0·00248076	+0·00005172	+0·00000000
4	+0·00159615	+0·00039137	−0·36841258
5	+0·00209440	+0·00007591	−0·19454958
6	+0·00157052	+0·00078263	+0·00000000
7	−0·00018703	+0·00041538	−0·39905220
8	+0·00157261	+0·00079218	−0·31922730
9	+0·00142075	+0·00081594	−0·06169292
10	−0·00004669	+0·00001855	+0·00000000
11	−0·00205664	+0·00047469	−0·26270994
12	+0·00021623	+0·00106392	−0·31599251
13	+0·00126970	+0·00109717	−0·09561702
14	+0·00027575	+0·00031571	+0·00482159
15	−0·00325406	+0·00012316	+0·00000000
16	−0·00120594	+0·00078901	−0·18893641
17	+0·00066127	+0·00094069	−0·09042406
18	+0·00045588	+0·00045115	+0·00623406
19	−0·00164483	+0·00069678	+0·00000000
20	−0·00026942	+0·00029706	−0·05285005
21	+0·00051428	+0·00048862	+0·00469040
22	−0·00031127	+0·00033951	+0·00000000
23	+0·00002811	+0·00000023	+0·00240733
24	−0·21049771	−0·21052632	+0·00000000

Table 1.—Deflections and Rotations of the Nodes on the Skew Bridge Analysed in Example 1.

Member	*Forces Tons*		*Moments Ton. Ft.*	
No.	*Shear*	*Torsion*	*End 1*	*End 2*
1 (1 → 2)	+11·67	−0·00	+ 0·00	+116·72
2 (2 → 4)	+11·67	−0·00	−116·72	+233·44
3 (4 → 7)	+11·57	−0·00	−233·44	+349·13
4 (3 → 5)	+13·23	−0·00	+ 0·00	+132·35
5 (5 → 8)	+13·44	−0·00	−132·35	+266·76
6 (6 → 9)	+ 5·90	+0·00	+ 0·00	+ 59·02
7 (2 → 3)	+ 0·00	−0·00	− 0·00	+ 0·00
8 (4 → 5)	+ 0·10	−0·00	− 0·00	+ 1·03
9 (5 → 6)	− 0·10	−0·00	− 1·03	+ 0·00
10 (7 → 11)	− 7·64	−0·00	−349·13	+272·69
11 (11 → 15)	−27·26	−0·00	−272·69	− 0·00
12 (8 → 12)	− 0·87	−0·00	−266·76	+258·09
13 (12 → 16)	−14·63	−0·00	−258·09	+111·75
14 (16 → 19)	−11·17	−0·00	−111·75	+ 0·00
15 (9 → 13)	+ 2·13	−0·00	− 59·02	+ 80·33
16 (13 → 17)	− 1·50	−0·00	− 80·33	+ 65·36
17 (17 → 20)	− 3·82	−0·00	− 65·36	+ 27·17
18 (20 → 22)	− 2·72	−0·00	− 27·17	− 0·00
19 (10 → 14)	− 0·81	−0·00	+ 0·00	− 8·15
20 (14 → 18)	+ 0·19	−0·00	+ 8·15	− 6·26
21 (18 → 21)	+ 0·58	−0·00	+ 6·26	− 0·48
22 (21 → 23)	+ 0·02	−0·00	+ 0·48	− 0·23
23 (23 → 24)	+ 0·02	−0·00	+ 0·23	− 0·00
24 (7 → 8)	+ 1·21	+0·00	+ 0·00	+ 12·08
25 (8 → 9)	− 2·49	−0·00	− 12·08	− 12·81
26 (9 → 10)	+ 1·28	−0·00	+ 12·81	− 0·00
27 (11 → 12)	+ 1·62	−0·00	− 0·00	+ 16·18
28 (12 → 13)	− 2·62	−0·00	− 16·18	− 10·04
29 (13 → 14)	+ 1·00	−0·00	− 10·04	− 0·00
30 (15 → 16)	+ 1·53	−0·00	− 0·00	+ 15·34
31 (16 → 17)	− 1·93	−0·00	− 15·35	− 3·93
32 (17 → 18)	+ 0·39	−0·00	+ 3·93	− 0·00
33 (19 → 20)	+ 0·55	−0·00	− 0·00	+ 5·51
34 (20 → 21)	− 0·55	−0·00	− 5·52	− 0·00
35 (22 → 23)	+ 0·00	−0·00	− 0·00	− 0·00

Table 2.—Forces and Moments at the Nodes of the Skew Bridge Analysed in Example 1.

$\mu = 0$, $G = \frac{1}{2}E$; and E has been taken as 2,000 tons/sq. in.

The floor system includes the beams framing the sides, and is restrained vertically only on level, unyielding supports at all the peripheral joints, which are at 10 ft. centres. Any other support system could have been used, for example corner supports only. The inclusive floor loading is taken as being uniformly distributed at 150 lb./sq. ft., and so carried by the top floor slab that it produces an equivalent floor loading of 3.35 tons at each of the internal joints.

In the analysis it has been sufficient to consider only one-quarter of the floor area, because of symmetry of structure and loading. At the edges no vertical displacements are allowed; at the centre-line joints the lateral rotations (i.e. rotations about the relevant centre-line itself) are set at zero.

Solution is possible by use of either the single or the partitioned frame programmes, and is printed-out in the usual way. The results of two analyses, the first including for torsion and the second neglecting it, are represented in Fig. 2(b) by the bending moment diagrams for the five different types of beam in the floor. The full and the dotted lines indicate the torsion and the torsion-less cases.

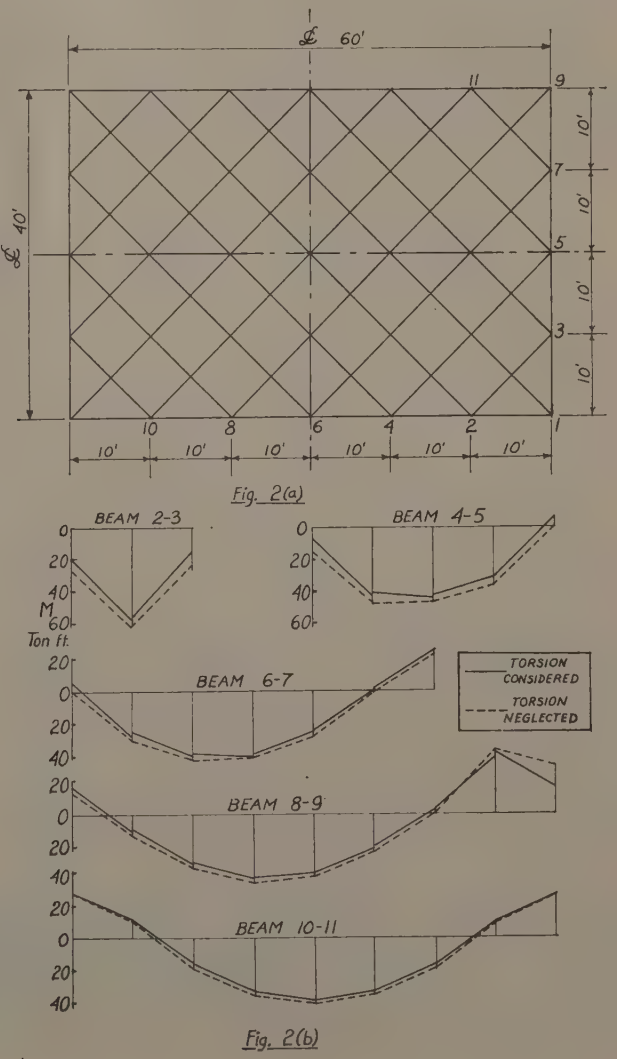


Fig. 2.—Bending moments for the diagrid floor of Example 2.

It will be realized that the assumption of zero for Poisson's ratio gives the maximum possible allowance for torsion; with this the discrepancy in the bending moment diagrams is at its greatest. The effect of including for torsion is to decrease the bending moments by up to about 10 per cent (in this case), but the members then have to be designed for full torsional strength. With torsional resistance occurring the vertical deflections decrease; in this case from 0.638 to 0.579 in., at the centre.

The effect of the side beams on the structural action can be appreciated from the bending moment diagrams for beams 6-7, 8-9 and 10-11. It is seen that reverse bending of considerable magnitude occurs at their ends.

Example 3. *Bridge with Main and Secondary Tee-beams*

The grid frameworks programme can be easily applied to the analysis of inter-connected Tee-and Ell-beams, but the effective flange widths must be assumed in advance, since this method may use but cannot itself provide such information. Research has shown that the effective flange width varies along the length of a Tee- or an Ell-beam, and depends on several factors.

A model phexiglass bridge was made and tested by Dr. Amin Ghali[7] in the course of his M.Sc. studies at Cairo University. The dimensions of this model are shown in Fig. 3(a), which also includes details of the cross-sections taken for the main and secondary beams in Ghali's revised analysis. The initial analysis was based on previous recommendations for the effective width of a Tee-beam, namely, the rib width plus 11 times the flange depth, but this was found to over-estimate the deflection under uniformly distributed loading. By using an approximate relationship between the second moments of area of the Tee-beams and the central deflection Ghali showed that the experimental deflections were closely predicted if the effective flange width was taken as the rib width plus 17 times the flange depth. This recommendation was adopted for the calculations performed by this electronic computer programme. The torsional rigidities of the main and secondary Tee-beams were calculated from a formula quoted by Dean Peabody[8], (which was also used by Ghali), and the value of Poisson's ratio was taken as 0.385 for this model material.

The deflection curves obtained for the main and secondary beams are shown plotted against the experimental values in Fig. 3(b). It will be noted that the theoretical deflections are now less than those actually measured, so it can be concluded that the formula, $B = 17t_s + b_o$, for the effective flange width B, in terms of the flange depth t_s and the rib width b_o, now gives an excessive value. Some compromise value might be more appropriate than the factor of 17 used for these calculations.

It is realized that it would be more satisfactory to compare stresses rather than deflections in such an investigation, but only deflections were measured in these model tests. However, this research does enable the formula $B = nt_s + b_o$ to be checked and revised by means of an alteration to the numerical factor, n; and though this gives little guidance to the actual variation in the effective flange widths throughout the bridge it is probably as far as a code of practice recommendation could go.

One or two further points should, perhaps, be mentioned. The main girders at the side behave as *symmetrical* Tee-beams only when the effective flange width is $10\frac{1}{2}\ t_s + b_o$; but the slightly eccentric

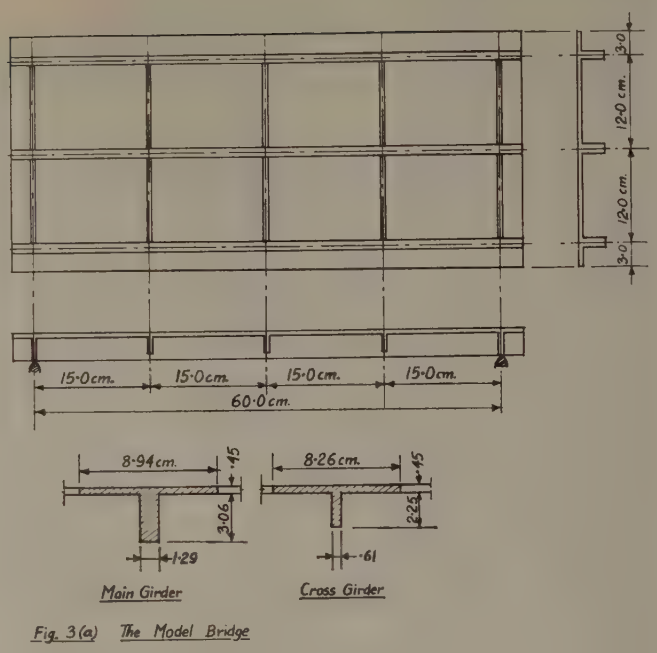


Fig. 3(a) The Model Bridge

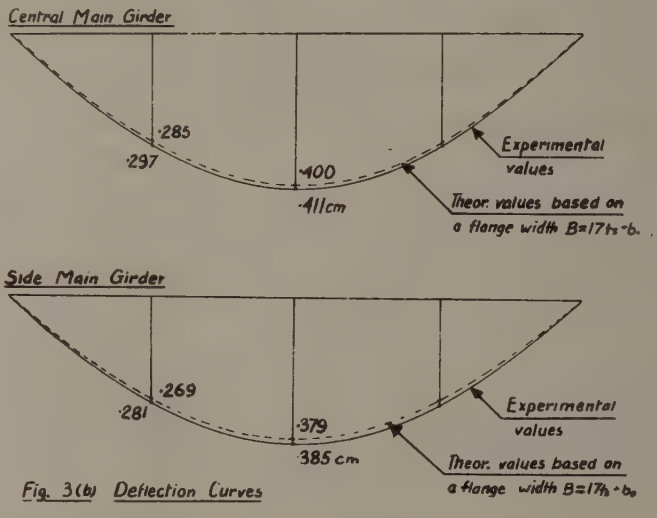


Fig. 3(b) Deflection Curves

Fig. 3.—Deflections for the Tee-beam bridge of Example 3

Tee-beams occurring at other flange widths are taken to act as being symmetrical. Also, the effect of the secondary Tee-beams above the supports was neglected by Ghali and again by the Authors—but could easily be included in a further computer analysis. Finally, the gaps in the decking between the main and secondary beams could be allowed for quite easily and would further stiffen the structure to some small extent. To allow for plate action, with two-way bending and twisting, however, the conditions explained in the next section have to be observed, but a corresponding analysis could be easily achieved by this computer method.

This example is included to show that the new programme will easily apply to the analysis and design of this type of structure, provided effective flange widths are known in advance. The programme could also be used along with Ghali's and further model tests, in a serious attempt to establish the most appropriate values for the numerical factors in the code of practice formulae for the effective flange widths of Tee- and Ell-beams.

Example 4. *Square Floor Slab on Flexible Edge Beams*

The parallel between the behaviour of grid frameworks and slabs has been appreciated for some time now, and Timoshenko[9] has already explained how isotropic and anisotropic plates may be considered as equivalent grid frameworks. In a fairly recent paper Taraporewalla[10] has used this parallel to solve orthogonal and diagrid floor systems as equivalent slabs. With this computer method for grid frameworks now available, however, it is convenient to reverse this procedure and to analyse slabs as equivalent grid frameworks. This generalised slope-deflection method is, in fact, closely related to the finite differences method for solving slabs and gives results to the same order of accuracy.

In ascribing flexural and torsional properties to an equivalent grid framework for an isotropic slab two conditions must be satisfied : (i) the flexural rigidity, EI, of an equivalent grid member must equal the flexural rigidity of the plate per unit width, D, times the spacing of the equivalent grid members, a and (ii) the torsional rigidity, GJ, must be taken as equal to the flexural rigidity, aD, in an equivalent grid member.

This first condition would be expected, but the second is less apparent. The torsional rigidity of a wide flat member, of breadth b much greater than its thickness t, is equal to $bt^3/3$, which equals $4 \times bt^3/12$, i.e. 4 EI. Now since $G = E/2(1 + \mu)$, where μ is Poisson's ratio, GJ for such a member equals $2\ EI/(1 + \mu)$. However, when plate action occurs this value for GJ has to be taken as aD : i.e. the GJ value has to be effectively halved with plate action, if $\mu = 0$. This condition has been used by Morice[11], but some writers have overlooked this necessary reduction.

With these conditions satisfied isotropic plates and slabs can be easily analysed, and the grid frameworks programme automatically prints out deflections, bending moments and torques at every node point. It has not been considered worth-while demonstrating this application ; instead, the problem of the corner-supported square slab with uniform edge beams, and with uniformly-distributed loading, has been considered as a more interesting example. The behaviour of this type of unit was the subject of a special study by Wood[12] of the Building Research Station, three or four years ago.

To enable results to be comparable with those obtained by Wood, Poisson's ratio was taken as zero, though any value could have been used with this new method. Each side of the square slab was divided into six equal parts, and the equivalent gridwork members were taken at the centres of the strips. The edge beams were assumed to have their neutral axes coincident with the neutral plane of the slab, and to have a flexural rigidity EI related to the DL value for the entire slab as defined by $\gamma = 2EI/DL$. The torsional rigidity of the edge beams is neglected in Wood's analysis ; this is equivalent to taking the ratio of the breadth b, to the depth, d of these beams as $1 : \infty$. The problem was solved for γ values $\frac{1}{6}$, $\frac{1}{3}$, 1·0, 2·0, 4·0 and 8·0 for this breadth to depth ratio $1 : \infty$, and also for breadth to depth ratios $1 : 5$, $1 : 3$ and $1 : 1$. The different sets of results enabled the effect of the torsional strength of the edge beam to be appreciated.

The deflections and bending moments at the centre of the slab are graphed against γ in Fig. 4(a) and (b) for the four different $b : d$ values considered. The values obtained by Wood are plotted in each figure ; it will be seen that these are all very close to the curve for $b : d = 1 : \infty$. Thus the computer solution by the equivalent grid framework gives virtually the same result as that found from the finite differences method used by Wood.

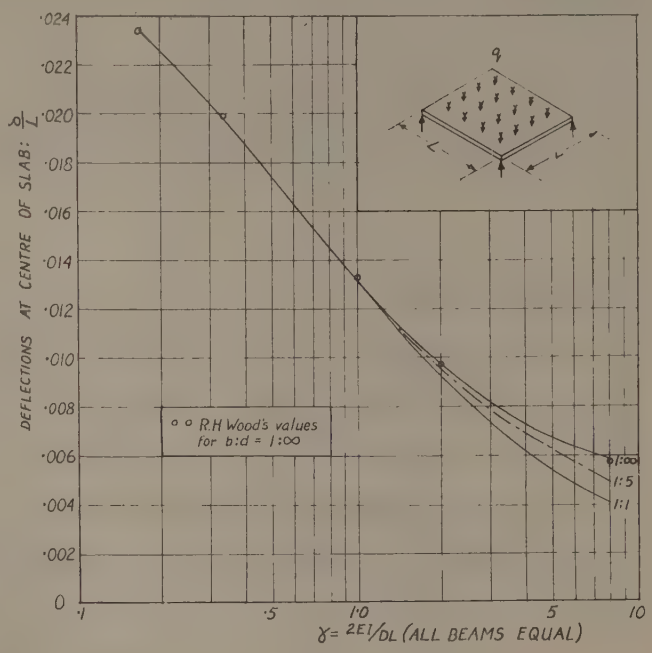


Fig. 4(a).—Square panel with uniform intensity of load $qL^3/D = 1{\cdot}000$. Deflections at centre of slab for various b:d ratios in beams.

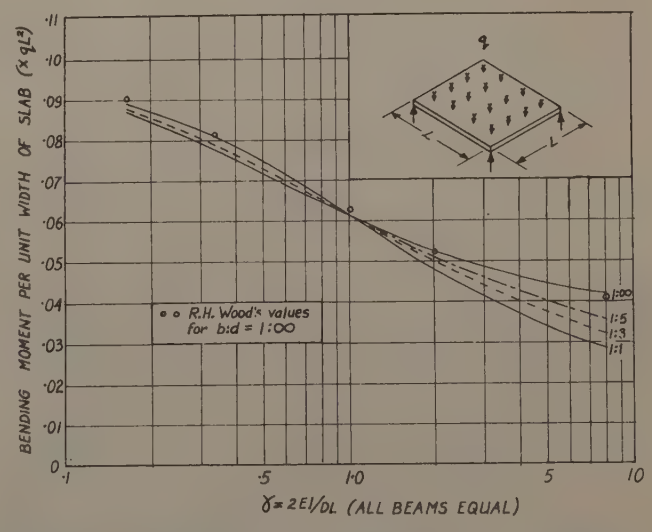


Fig. 4(b). — Square panel with uniform loading — Bending moments in centre of slab for various b:d ratios in beams.

Fig. 4.—Deflections and bending moments for corner-supported square slabs, with flexible edge-beams.

It should be noted that the edge beam breadth, b, has not been related to the length, L, of the side of the slab. This relationship could be allowed for and would result in a slightly modified solution at $b : d$ values 1 : 5, 1 : 3 and 1 : 1, since the members representing the edge strips of the slab would need to have their EI and GJ values reduced by the factor :

$$\left(\frac{L}{6} - \frac{b}{2}\right) : \frac{L}{6} = (1 - 3b/L),$$

as the edge strip width would then be reduced.

In actual construction the slab would most probably connect in with the top of the beams. The resulting Ell-beam action could be allowed for quite easily if the effective flange width was assumed. The torsional strength of the Ell-beam could be taken at its full value even though it includes part of the slab, with little resultant error, since the torsional effect is really quite small. If desired, however, the torsional strength of the Ell-beam could be taken as the sum of the full value for the rib of the beam (extending to the top surface), plus the reduced value for the additional flange. This would probably give a more accurate analysis, provided the effective flange width was estimated correctly.

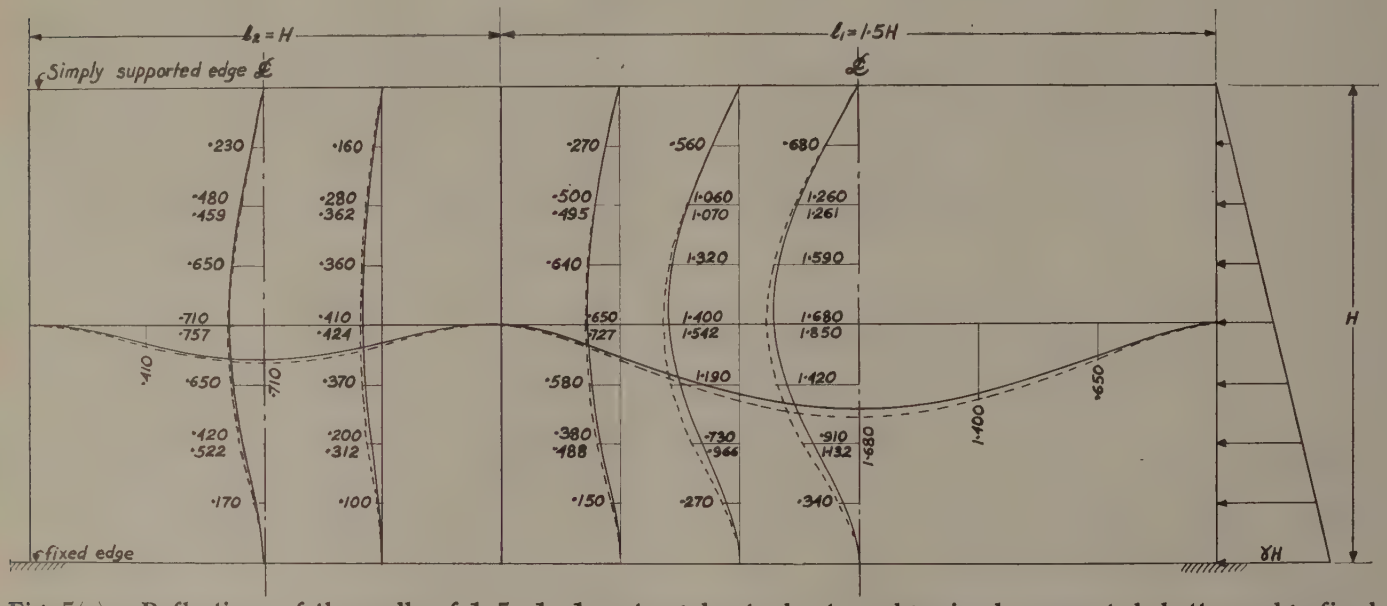


Fig. 5(a).—Deflections of the walls of 1·5 : 1 : 1 rectangular tank ; top edge simply supported, bottom edge fixed. Upper values from computer analysis, lower, where available, experimental. The values are multiples of 10^{-3}. $\frac{\gamma H^5}{D}$.

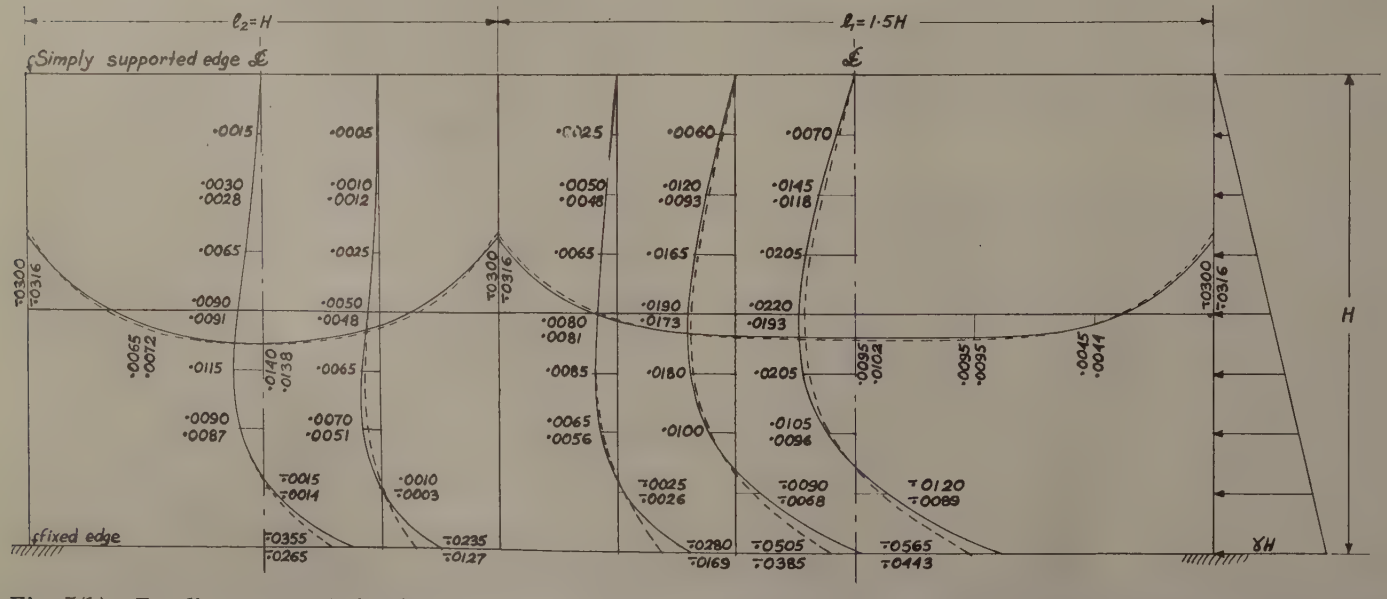


Fig. 5(b)—Bending moments in the walls of a 1·5 : 1 : 1 rectangular tank ; top edge simply supported, bottom edge fixed. Upper values from computer analysis, lower where available, experimental. The values are multiples of γH^3.

Fig. 5.—Deflections and bending moments for the walls of a rectangular tank.

It will be appreciated that this computer method would apply to the rectangular floor slab of constant or variable thickness, supported by beams with any variation in their sections, and for any loading and support conditions, however disposed. In the general case a full analysis would be required since symmetry of structure and loading would not occur, but the programme allowing for partitioning would apply to sufficient accuracy in all such cases.

Example 5. *Rectangular Water Tank in Reinforced Concrete*

Rectangular tanks are composed of inter-connected rectangular slabs and can be analysed on the assumption of the theory for thin plates applying, provided there is insufficient deflection to develop appreciable membrane action. Tanks in reinforced concrete are usually considered to satisfy these conditions, and the codes of practice allow the sections to be considered as unreinforced but completely effective, for the purpose of analysis.

If the rectangular tank has free, hinged or fixed support conditions at its top and bottom edges, the structural behaviour of the sides can be analysed. There is little difficulty in establishing the support conditions ; those for the horizontal edges are known, the vertical edge allows horizontal rotations only and the vertical centres of the sides can deflect and rotate vertically, but not horizontally. Only two connected half-sides need to be considered, if the loading is symmetrical.

The rectangular tank has been investigated both experimentally and theoretically by Ghali[13] in his Ph.D. studies, when the senior Author acted as his supervisor. The conjoint part of this work has already been published [14] and explains the finite differences method of analysis for a rectangular tank fixed at the base and free at the top edge. The same tank, with length, breadth, depth proportions 1·5 : 1 : 1, but with its top edge hinged and the base again fixed, has been used as a further example here. A strip width of one-fourth of the height was taken as sufficient and the grid frameworks method applied. Since it was intended to compare results with those obtained experimentally, the value of Poisson's ratio was taken as that measured for the phexiglass model, that is 0·385.

The deflections and bending moments obtained by means of this electronic computer method are compared with those obtained experimentally, in Figs. 5(a) and (b). It will be seen that the agreement between the deflections is quite good, the discrepancy being consistent with a possibility of slightly imperfect fixity at the jointed edges. Also, the bending moments agree quite well, except for the vertical fixing moments at the base. A similar amount of error was found by Ghali, using the finite differences method, and is explained as being most likely experimental, arising from various causes, such as imperfect fixity, and strain measurements with short (and therefore less accurate) electric resistance gauges applied where the strain changes rapidly.

The grid frameworks analysis can therefore be considered quite satisfactory for this type of problem. It could clearly be applied to tanks of varying section, and even to square bunkers with inverted pyramidal bases, if the lateral loading was known or assumed. Since the partitioning method will only apply *linearly* in the present programmes it is not yet possible to allow for interaction between tank walls and a common base.

5. Conclusion

This new electronic computer programme has now been applied successfully to the analysis of several grid frameworks and related structures, and further applications are undoubtedly possible. It is hoped that this paper will stimulate greater interest in structural analysis by means of the electronic computer.

6. Acknowledgments

The Authors would like to place on record their appreciation of much of the previous research on this type of structure, and particularly of the work they have used for comparison and verification in this paper. They are especially indebted to Dr. Ghali, a former colleague of the senior Author and now a lecturer at the University of Cairo, for the examples drawn from his M.Sc. and Ph.D. theses.

The earlier stages of programme development were greatly facilitated by the generous assistance of Mr. Rooney, then with Babcock and Wilcox Ltd. The various analyses were performed on the Ferranti Pegasus machine in the University of Leeds Computing Laboratory and the Director and staff there helped this work in many ways. The Authors are glad to acknowledge all this kindly co-operation.

References

1 Livesley, R. K., " Analysis of Rigid Frames by an Electronic Digital Computer," *Engineering*, vol. 176, pages 230 and 277, August, 1953.
2 Livesley, R. K., and Charlton T. M.. " Analysis of Rigid Frames by an Electronic Digital Computer," *Engineering*, vol. 177, page 239, February, 1954.
3 Livesley, R. K., " The Application of an Electronic Digital Computer to some Problems of Structural Analysis," *The Structural Engineer*, January, 1956.
4 Ferranti Ltd. " A Single Plane Framework Programme (Livesley Method)," List CS 194, April, 1958.
5 Hendry, A. W. and L. G. Jaeger, " The Analysis of Grid Frameworks and Related Structures." Chatto and Windus, 1958.
6 Lightfoot, E., and Sawko F., " Structural Frame Analysis by Electronic Computer; Grid Frameworks Resolved by Generalised Slope Deflection," *Engineering*, vol. 182, page 18, January, 1959.
7 Ghali, Amin, " Structural Analysis of Monolithic Girder Road Bridges." M.Sc. thesis. Cairo University, 1954.
8 Peabody, Dean Junr., " The Design of Reinforced Concrete Structures." 2nd Edition.
9 Timoshenko, S., Theory of Plates and Shells." McGraw Hill, 1942.
10 Taraporewalla, K. J., " Design of Grid and Diagrid Systems on the Analogy of Design of Plates." *The Structural Engineer*, April, 1958.
11 Morice, P. B., " The Analysis of Right Bridge Decks Subjected to Abnormal Loading." Cement and Concrete Association, 1956.
12 Wood, R. H., " Studies in Composite Construction ; Part II, The Interaction of Floors and Beams in Multi-Storey Buildings." H.M.S.O. 1955.
13 Ghali, Amin, " The Structural Analysis of Circular and Rectangular Concrete Tanks." Ph. D. thesis. University of Leeds, 1957.
14 Lightfoot, E., and Ghali, Amin " The Analysis of Rectangular Tanks," " *Proceedings of the Institution of Structural Engineers Fiftieth Anniversary Conference*," October, 1958.

(3) Elastic Critical Loads of Multi-bay Pitched Roof Portal Frames with Rigid External Stanchions

by D. M. Brotton, B.Sc., Ph.D., A.M.I.Struct.E.

Synopsis

The paper contains the results of an investigation into the elastic critical loads of multi-bay pitched roof portal frames using an electronic digital computer. The variables considered are :

(a) The number of bays.

(b) The ratio $\frac{\text{Span}}{\text{Stanchion height}}$

(c) The angle of inclination of the rafters.

(d) The ratio $\frac{\text{Inertia of Stanchion}}{\text{Inertia of Rafter}}$

(e) The end fixity of the internal stanchions.

Notation

P	Axial load in member.
P_E	Euler load of member.
I	Moment of inertia of member.
k	Elastic stiffness of member $= \frac{EI}{L}$
L	Length of member.
s, c, m	Stability functions for member (tab. in ref. 6).
l	Span of each bay.
h_1	Height of internal columns
h_2	Height from eaves to apex.
θ	Rotation of joint.
δ	Lateral displacement at eaves joint.

Introduction

The elastic critical load is that value of the applied load at which a framework would offer no resistance to a small disturbance, the entire framework remaining elastic.

The stiffness and carry-over factors for an isolated member depend upon the axial force it sustains, so the first stage in calculating the stiffness of a framework is an elastic analysis of the frame to determine the axial forces in the members under the particular value of the applied load. A second analysis using the stiffness and carry-over factors based on the previously determined axial forces gives the deflection of the frame due to a small disturbing force. The process is convergent and further analyses will give the final value of the deflection. The frame stiffness is given by the equation

$$F = K\delta$$

where F is the disturbing force,
K is the frame stiffness,
δ is the final value of the deflection.

The sequence can be repeated for a series of increasing values of the load parameter thus enabling a stiffness curve to be drawn and the zero stiffness or elastic critical load of the framework to be obtained.

Dr. R. K. Livesley prepared a computer programme which carried out a normal elastic frame analysis[1] and later modified it to take account of stability effects[2]. This programme which was written for the Ferranti Mark 1 Computer has been used to obtain the results which follow.

Stiffness Curves

The shape of a stiffness curve depends upon the relation between the critical mode of the structure and the displacements due to the disturbing force. For a single member or a simple structure it is possible with a suitably placed single disturbing force or moment to excite a large component of the primary buckling mode ; the resulting stiffness curve will then be nearly straight. With more complex structures, however, stiffness curves obtained by using a single disturbing force may be considerably curved making extrapolation to determine the elastic critical load more difficult. There are three methods which can be adopted to help overcome this difficulty :

(a) To use more than one disturbing force combined in such a manner as to minimise the curvature of the stiffness curve[3].

(b) To use one of the techniques which has been developed for the extrapolation of stiffness curves[4 5].

(c) To carry out the stiffness analysis for values of the load parameter as close as possible to the elastic critical load.

In using an electronic computer it is a comparatively simple matter to alter the value of the load parameter. Method (*c*) has therefore been used throughout. As a general rule, three analyses were required to ensure convergence and these were repeated for five or six values of the load parameter in order to complete each stiffness curve.

The present results are restricted to frames with rigid external stanchions but it is hoped to extend the range later to include frames with external stanchions which do not inhibit sway of the frames as a whole. The results will be presented in groups in each of which consideration will be given to not more than two variables.

Series A.1

Frames with Internal Stanchions pinned top and bottom

Variables : No. of bays, $\frac{\textit{Span}}{\textit{Stanchion height}}$ *Ratio*

For the frames in this series a small horizontal disturbing force at the top of an internal stanchion induces an overturning effect in the stanchion which is resisted by the rafter which acts as a horizontal

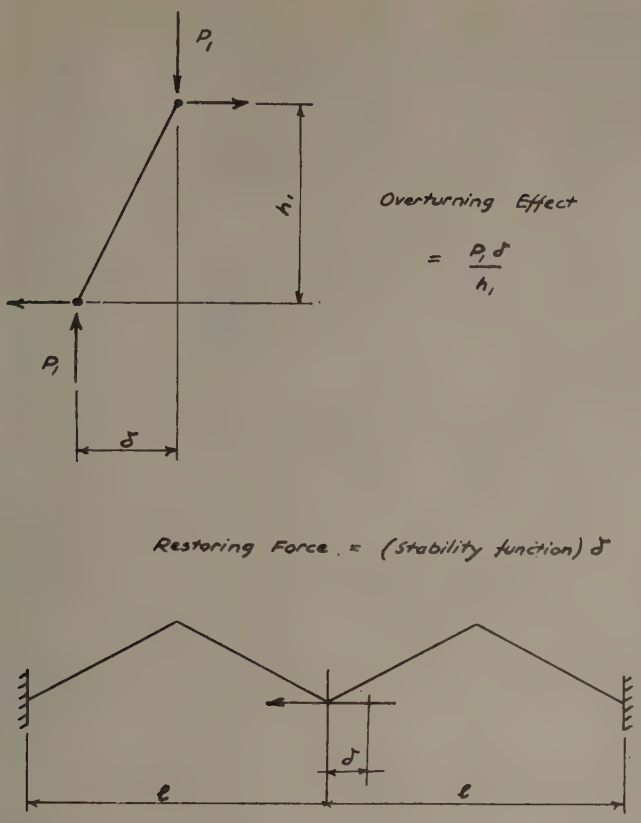


Fig. 1.

spring with two ends rigidly held. The sway critical condition arises when the "overturning effect" is equal to the "spring stiffness." These effects are shown in Fig. 1.

The computer has been used to determine the spring stiffness of the rafters of 2, 3, 4, 5 and 10 bay frames having an angle of inclination of the rafter of $22\frac{1}{2}°$. The curve for a 3 bay frame is plotted non-dimensionally in Fig. 2. The overturning effect is a linear function of the applied load and the straight lines superimposed on the rafter stiffness curve in Fig. 2 give its value for a series of values of $\frac{l}{h_1}$ ratio. The sway critical load of a frame is therefore given by the intersection of the particular overturning effect line with the rafter stiffness curve.

For frames with long columns, i.e. for small values of $\frac{l}{h_1}$, the axial load in the column attains its P_E value before the sway critical load of the frame is reached. The critical mode becomes the local one of column buckling and the critical loads are given by the intersections of the overturning effect lines with the local column buckling curve shown in Fig. 2.

Similar graphs have been obtained for frames with other than three bays. Comparison of the rafter stiffness curves shows that they increase in curvature with increasing number of bays. Tangents drawn to the curves at the zero load point would however intersect the load axis at approximately the same point. The increasing curvature is a result of the increasing influence of a third buckling mode, "the arch mode" in which adjacent joints rotate in opposite directions. This is due to the increasing remoteness of the restraining effect of the rigidly built in ends. Better stiffness curves could have been obtained by using a disturbance comprising both a horizontal force and a rotation acting on the joint at the top of an internal column.

Fig. 3 shows curves giving the elastic critical loads of multi-bay frames with varying $\frac{l}{h_1}$ value. They are plotted in terms of the $\frac{P}{P_E}$ ratio of the rafters. It can be seen that the curves consist of two separate parts, a common part for low values of $\frac{l}{h_1}$ ratio which governs the internal column buckling mode and is parabolic, also individual curves for frames with different numbers of bays which govern the sway critical load. The column buckling mode curve shown in Fig. 3 is for a column of the same section as that of the rafter. However a family of similar curves could be drawn, each corresponding to a different value of the ratio $\frac{\text{Inertia of stanchion}}{\text{Inertia of rafter}}$.

In the range of frames where the sway mode is critical, the elastic critical load reduces with increasing values of $\frac{l}{h_1}$ ratio. This would be expected since the

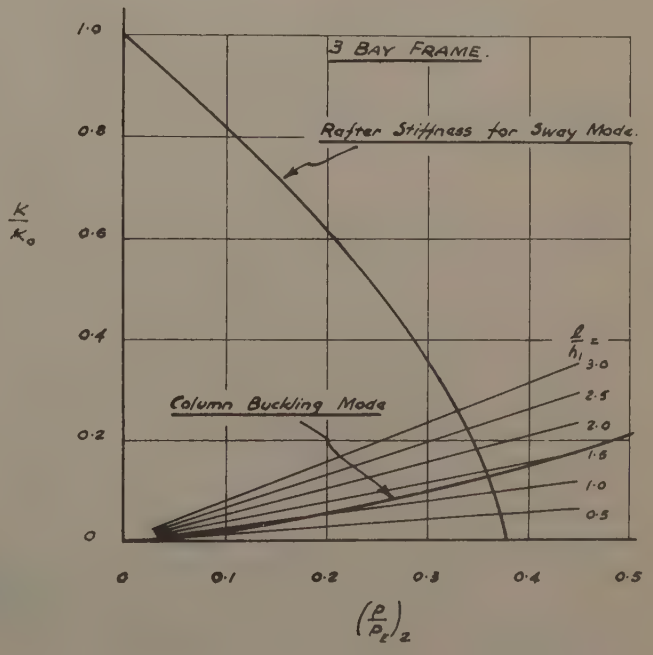


Fig. 2.

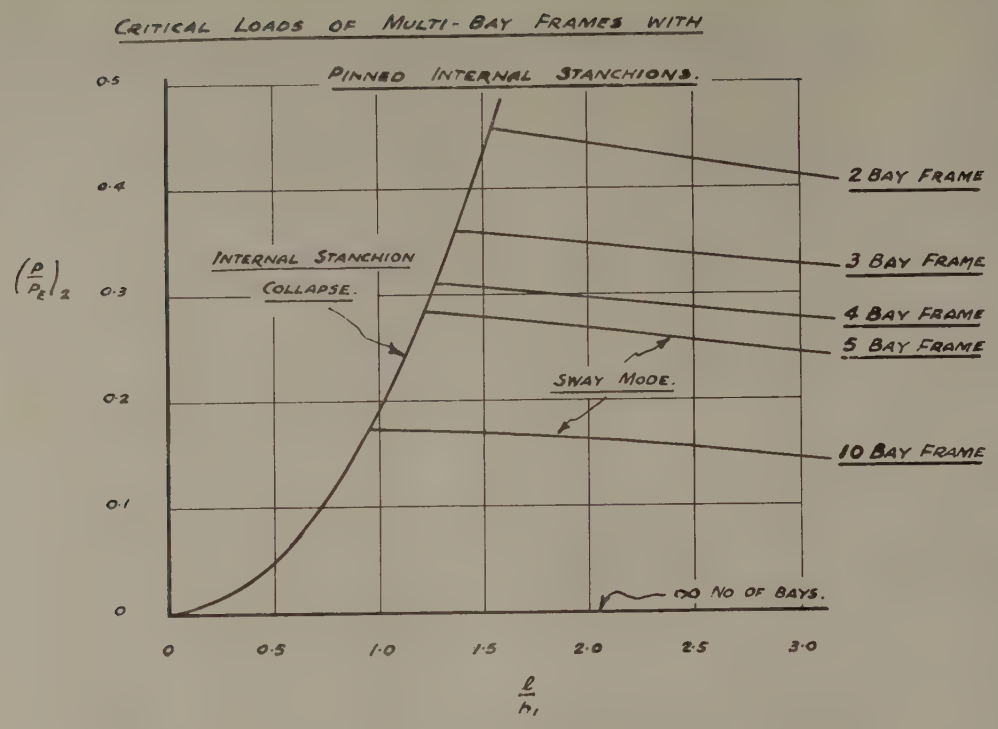


Fig. 3.

overturning effect is inversely proportional to h_1 and this has a large influence on the critical load of the frame as a whole.

A rafter having an infinite number of bays would have zero "spring stiffness." The sway critical load would therefore be zero and this is shown on Fig. 3.

Fig. 4 shows the same results, the critical loads being plotted in terms of the $\frac{P}{P_E}$ ratio for the columns. The internal column buckling mode appears as a horizontal straight line and the sway mode as a series of hyperbolic type curves.

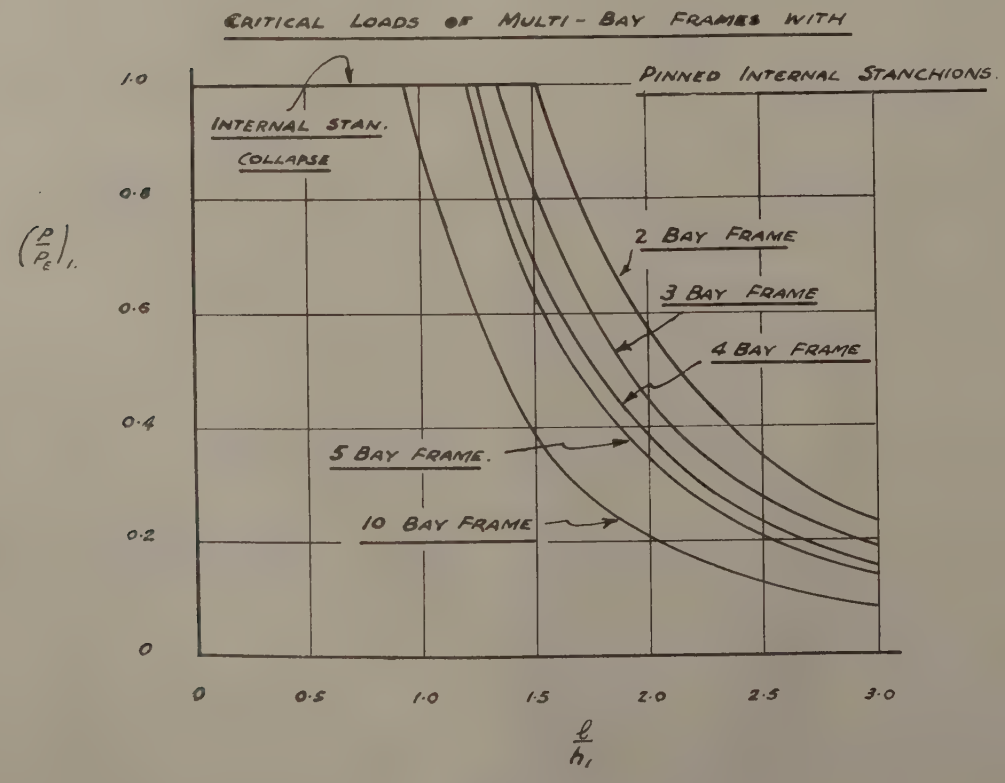


Fig. 4.

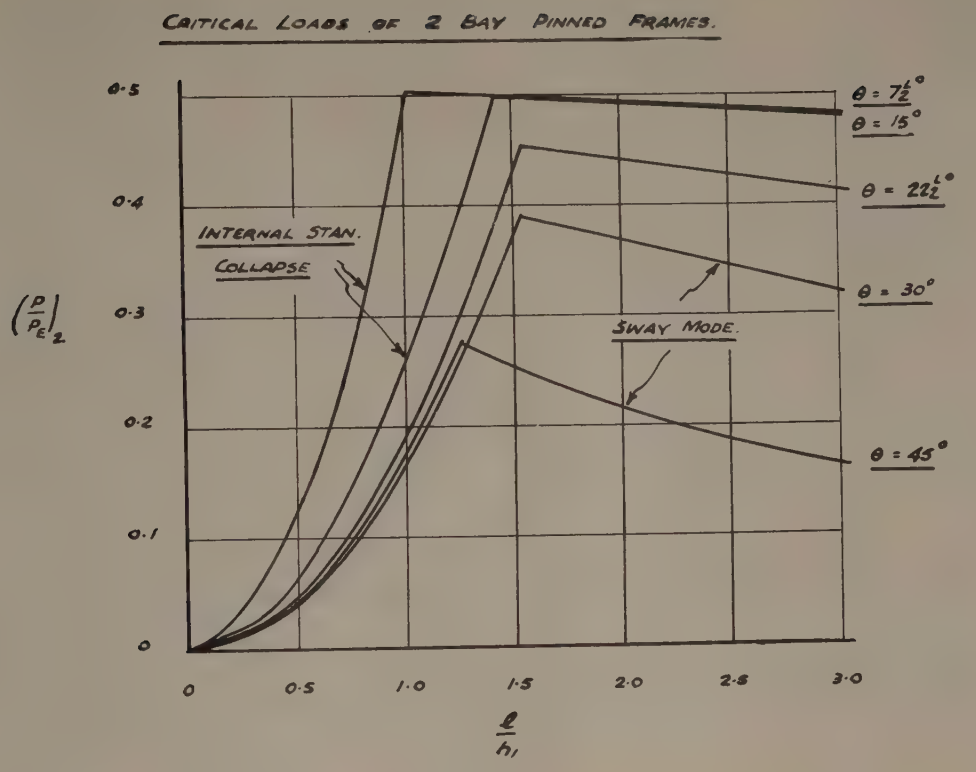

CRITICAL LOADS OF 2 BAY PINNED FRAMES.
0·5
0·4
0·3
0·2
0·1
0
$\left(\frac{P}{P_E}\right)_2$
INTERNAL STAN.
COLLAPSE
SWAY MODE.
θ = 7½°
θ = 15°
θ = 22½°
θ = 30°
θ = 45°
0
0·5
1·0
1·5
2·0
2·5
3·0
$\frac{\ell}{h_1}$

Fig. 5.

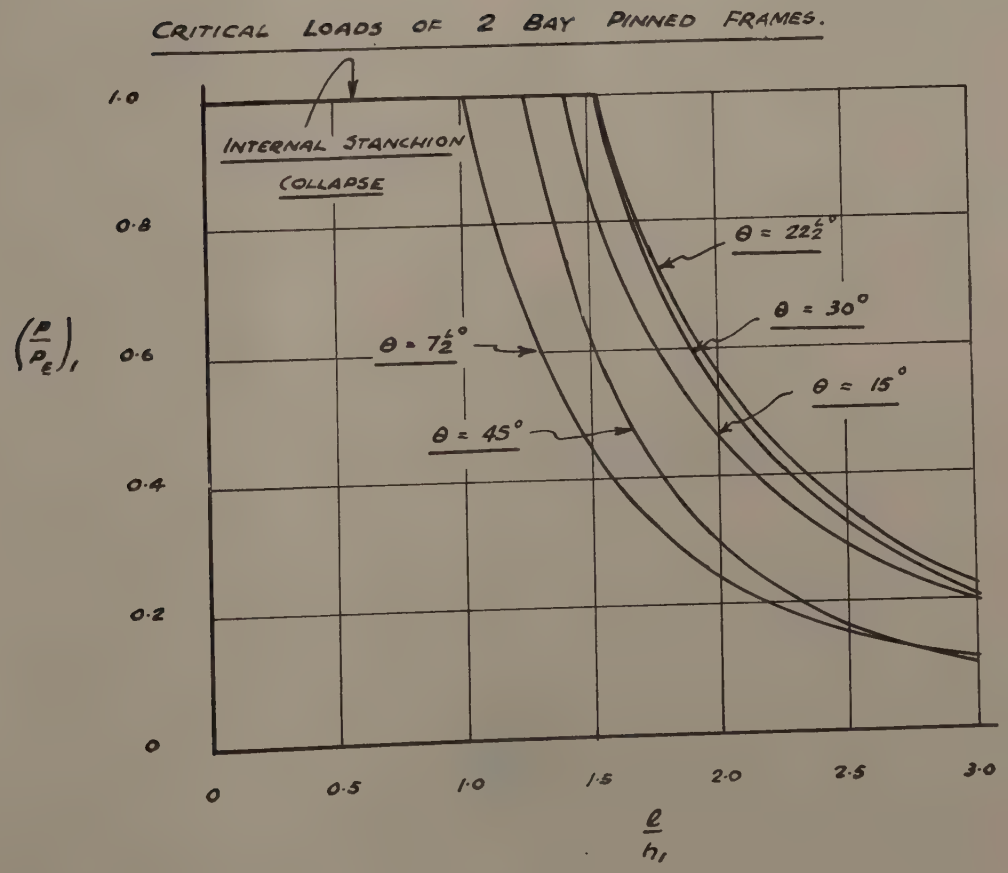

CRITICAL LOADS OF 2 BAY PINNED FRAMES.
1·0
0·8
0·6
0·4
0·2
0
$\left(\frac{P}{P_E}\right)_1$
INTERNAL STANCHION
COLLAPSE
θ = 22½°
θ = 30°
θ = 15°
θ = 7½°
θ = 45°
0
0·5
1·0
1·5
2·0
2·5
3·0
$\frac{\ell}{h_1}$

Fig. 6.

Series A.2

Frames with Internal Stanchions pinned top and bottom

Variables : $\frac{l}{h_1}$ *ratio, angle of inclination of the rafters*

This series consists entirely of 2 bay frames with angles of inclination of the rafters of $7\frac{1}{2}°$, 15°, $22\frac{1}{2}°$, 30° and 45°. The results which are of the same general shape as the previous series are shown in Fig. 5, the critical loads being given in terms of the $\frac{P}{P_E}$ value for the rafter.

The ratio of the $\frac{P}{P_E}$ value of the rafters and internal columns depends upon the angle of inclination of the rafters. The effect on the elastic critical load of variations in the rafter inclination is therefore better presented by plotting in terms of $\frac{P}{P_E}$ values for the internal columns since these are directly proportional to the applied load and independent of the rafter inclination. This is shown in Fig. 6.

It is apparent from Fig. 6 that frames with a rafter inclination of approximately $22\frac{1}{2}°$ have the largest critical loads. The question of relative economics is not pursued any further here since the elastic critical load presents only part of the picture. Considerations of plastic collapse and the combined effects of plasticity and stability are necessary to complete it.

Series B.1

Frames with Rigid Internal Stanchions

Variables : $\frac{l}{h_1}$ *ratio, number of bays*

The group of frames considered here is similar to that in Series A.1, differing only in the end fixity of the internal stanchions. The frames have become completely continuous structures and the effect of this has been to require separate stiffness curves for each value of $\frac{l}{h_1}$. The computer has been used to obtain these stiffness curves for 2, 3, 4, 5 and 10 bay frames and for a series of $\frac{l}{h_1}$ values varying from 0·5 to 3·0, the disturbing force in all cases being a horizontal force acting on one of the valley joints, at or near the centre.

A family of stiffness curves for 3 bay frames with varying $\frac{l}{h_1}$ value is shown in Fig. 7. The influence of

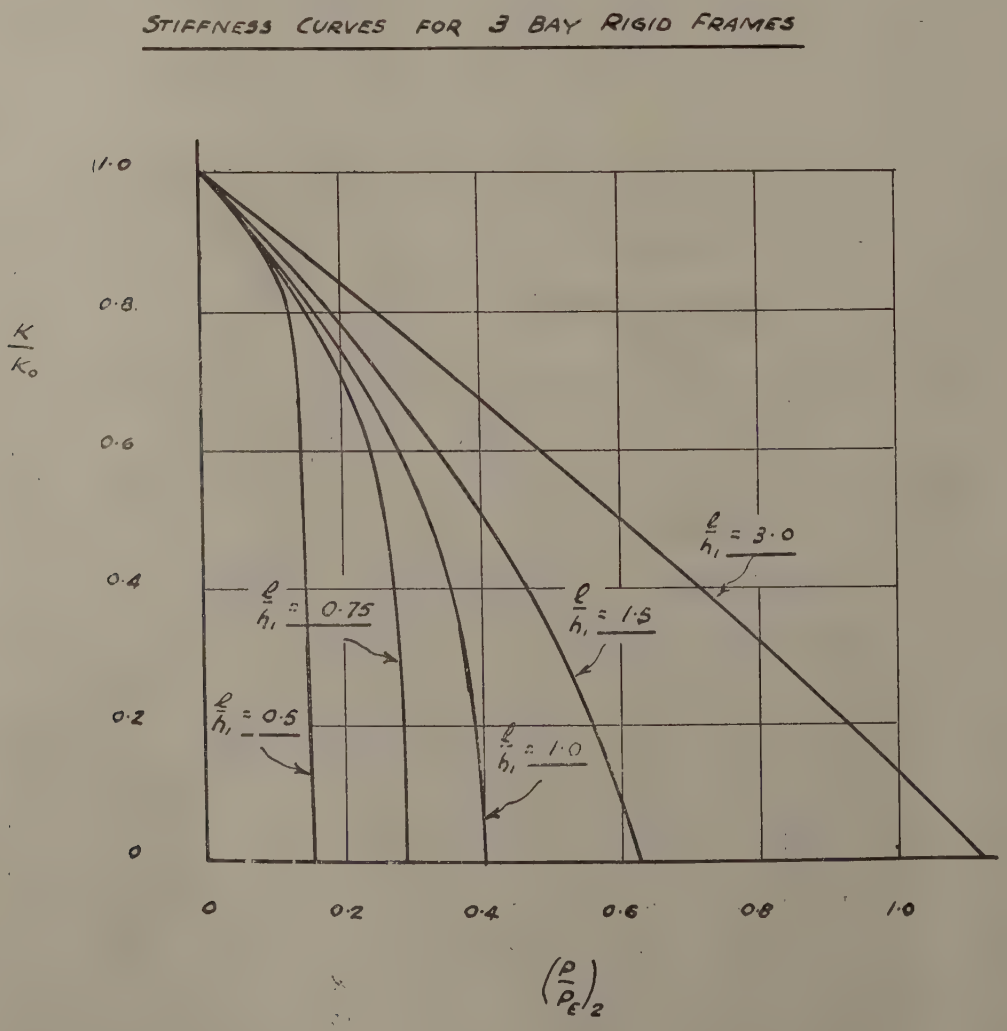


Fig. 7.

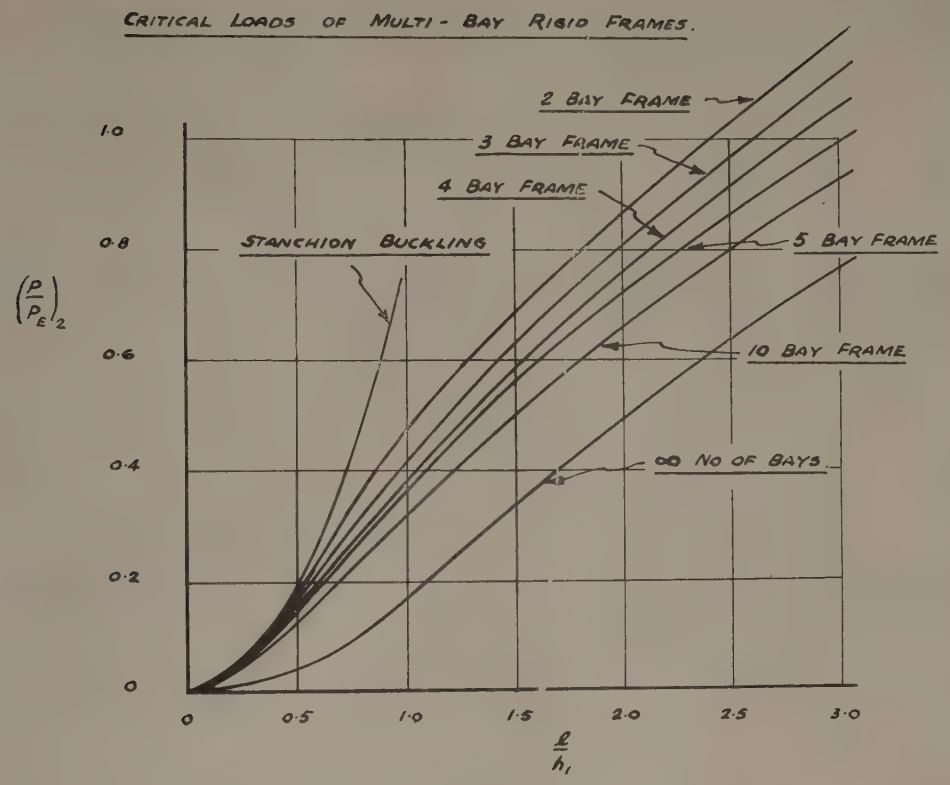


Fig. 8.

the local column buckling mode has been to depress the curves, those for low $\frac{l}{h_1}$ values drop extremely rapidly. The transition from frames for which the critical mode is the sway mode to those for which it is the local column buckling mode is gradual and over most of the range the influence of both is felt.

The curves shown in Fig. 8 give the elastic critical loads for frames with rigid internal stanchions as a function of their $\frac{l}{h_1}$ value. The curve representing internal column buckling and corresponding to $\frac{P}{P_E}$ for the column equal to 4 is also shown. Its influence on the critical load curves is apparent.

In the region where the sway mode is predominant the critical load increases with increasing values of $\frac{l}{h_1}$ ratio whereas with the frames of Series A.1 with pinned columns the reverse effect is produced. This can be clearly understood since overturning effect previously mentioned increases with increasing $\frac{l}{h_1}$ ratio and has an adverse effect on the critical loads of the pinned frames whereas the additional stiffness of rigid internal stanchions increases with increasing $\frac{l}{h_1}$ value.

The decrease in the critical load with increasing number of bays is much less marked than in frames with pinned internal stanchions. The curves approach a lower limit i.e. the critical loads for frames with an infinite number of bays. This is also shown in Fig. 8. The calculation of this curve was done manually as shown below :

The Elastic Critical load for Rigid Frames with an infinite number of bays

The calculation is based on the assumption that for an infinitely long framework the outer end effects will have decayed and therefore adjacent bays near the centre will distort identically. In order to simplify the calculation a small horizontal disturbing force has been applied at each valley joint.

The critical condition is

$$s_1 \left\{ m_1 \left(1 + c_1\right) - 2 \right\} - 4 s_2 \left(1 - c_2^2\right) \frac{k_2}{k_1} = 0$$

(See appendix).

The actual critical loads have been found by a trial and error substitution in the above equation for a series of $\frac{P}{P_E}$ values.

The curve is of the same general shape as those for a finite number of bays and intermediate values can be easily obtained by a suitable interpolation.

The results of Fig. 8 are replotted in Fig. 9, the critical loads being given in terms of $\frac{P}{P_E}$ for the internal columns. Fig. 9 shows that for large values of $\frac{l}{h_1}$ increasing the number of bays does not cause a very large reduction in the critical loads, the difference being more pronounced for low values of $\frac{l}{h_1}$. The critical loads at zero $\frac{l}{h_1}$ value may require some explanation : for a finite number of bays the spring stiffness and rotational stiffness tend to infinity and the collapse tends to that of a column, position and

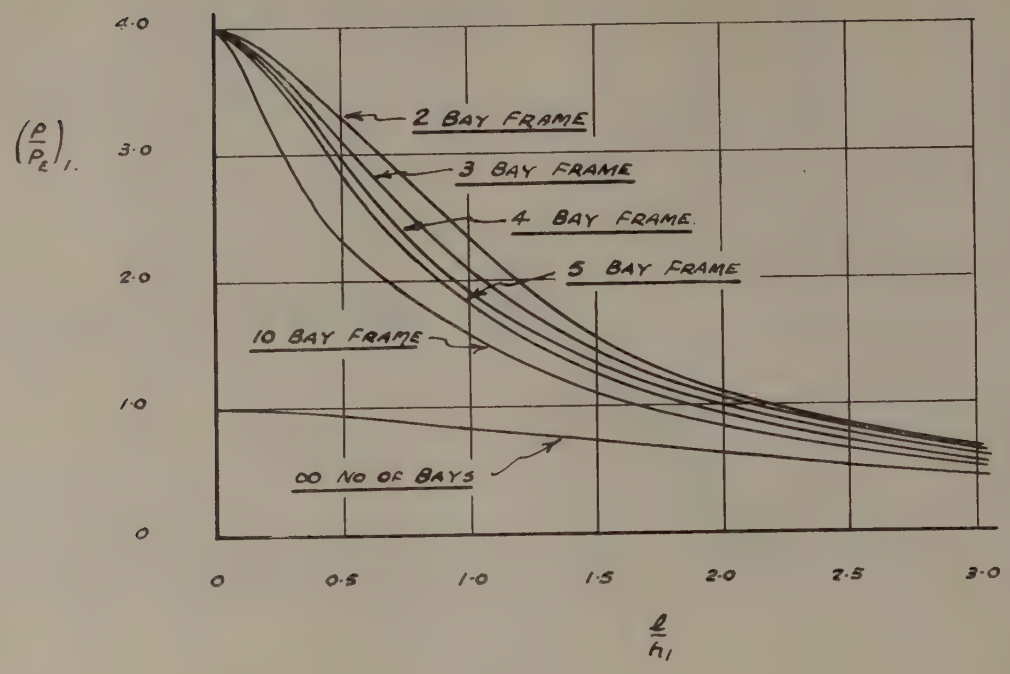

CRITICAL LOADS OF MULTI-BAY RIGID FRAMES.
4·0
3·0
2·0
1·0
0
$\left(\frac{P}{P_E}\right)_1$
2 BAY FRAME
3 BAY FRAME
4 BAY FRAME
5 BAY FRAME
10 BAY FRAME
∞ NO OF BAYS
0
0·5
1·0
1·5
2·0
2·5
3·0
$\frac{l}{h_1}$

Fig. 9.

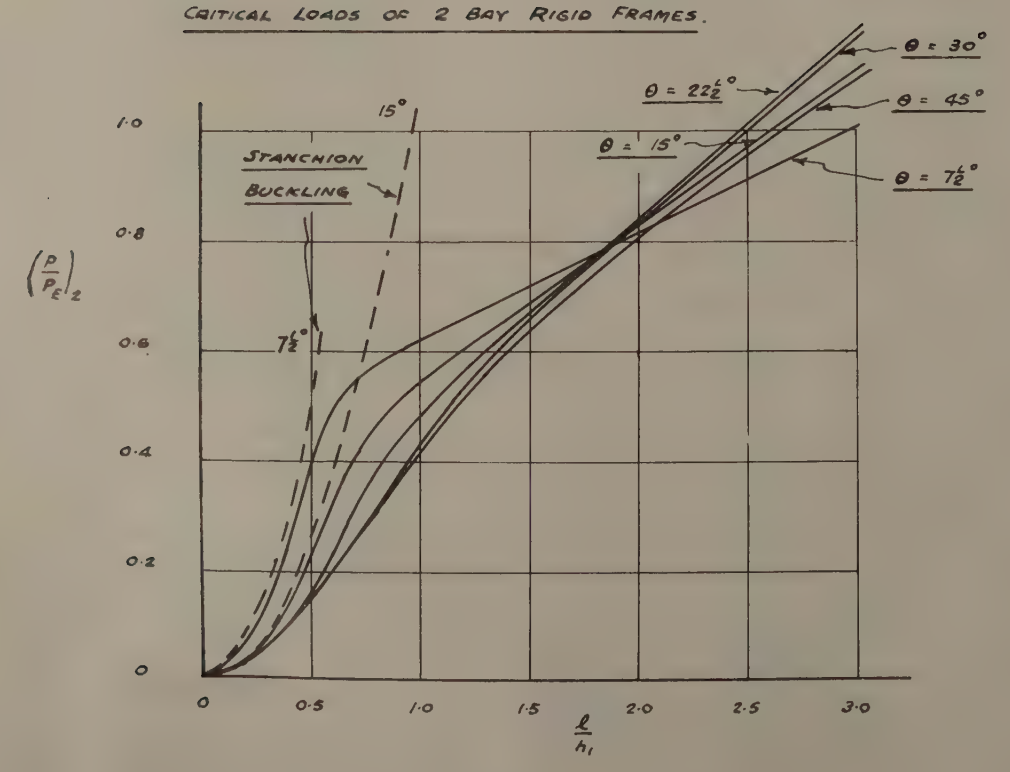

CRITICAL LOADS OF 2 BAY RIGID FRAMES.
θ = 30°
θ = 22½°
θ = 45°
θ = 15°
θ = 7½°
15°
STANCHION BUCKLING
7½°
1·0
0·8
0·6
0·4
0·2
0
$\left(\frac{P}{P_E}\right)_2$
0
0·5
1·0
1·5
2·0
2·5
3·0
$\frac{l}{h_1}$

Fig. 10.

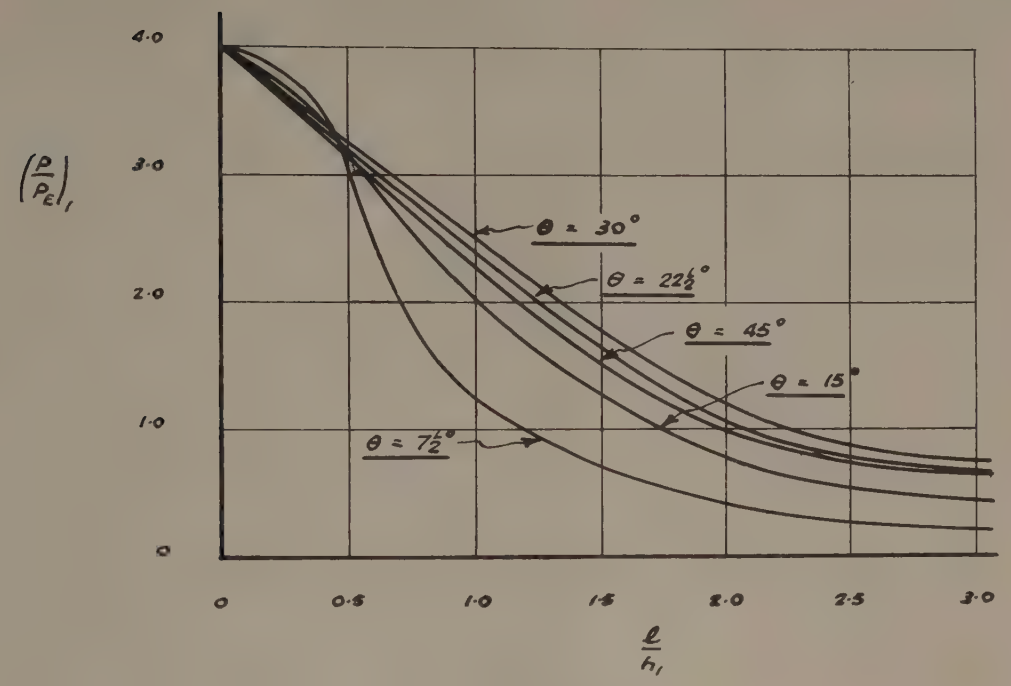


Fig. 11.

direction fixed at both ends, i.e. $\frac{P}{P_E} = 4$. For an infinite number of bays however the spring stiffness tends to zero while the rotational stiffness remains infinite and the collapse tends to that of a column, position and direction fixed at both ends but free to sway i.e. $\frac{P}{P_E} = 1$.

Series B.2

Frames with Rigid Internal Stanchions

Variables : $\frac{l}{h_1}$ *ratio, angle of inclination of the rafters*

This series corresponds to Series A.2 for frames with pinned internal stanchions. All the frames have two bays and angles of inclination of the rafters of 7½°, 15°, 22½°, 30° and 45° are considered. The critical loads in terms of the $\frac{P}{P_E}$ value for the rafters is shown in Fig. 10 as a function of $\frac{l}{h_1}$ value. Curves corresponding to the local buckling of the internal columns are also shown. It can be seen that the influence of column buckling on the critical load is much more pronounced for frames with shallow rafter slope.

The results are plotted in terms of $\frac{P}{P_E}$ value for the column in Fig. 11 to enable a better comparison to be made. Over most of the range of $\frac{l}{h_1}$ values frames with a rafter slope of 30° have the largest critical loads but for $\frac{l}{h_1}$ less than 0·5 where the column buckling mode is predominant, the critical load is largest for frames with smallest rafter slopes. There is little difference between the critical loads of frames with rafter slopes between 22½° and 45° over the complete range of $\frac{l}{h_1}$ values.

Series B.3

Frames with Rigid Internal Stanchions

Variables : $\frac{l}{h_1}$ *ratio, Ratio of* $\frac{\text{Column Inertia}}{\text{Rafter Inertia}}$

The frames considered in this series are all two bay frames with an angle of inclination of the rafter of 22½°. The computer has been used to determine the critical loads of frames with $\frac{I_1}{I_2}$ values varying between 0·5 and 3·0. This was done in the simplest way, by altering the inertia of the columns on some of the previous data tapes. The results are plotted in Fig. 12 for values of $\frac{l}{h_1}$ from zero to 3·0, the critical loads being given in terms of $\frac{P}{P_E}$ for the rafters. Fig. 12 shows that for frames with the same section for the rafters, a change in the inertia of the columns has a more significant effect on the critical load for small $\frac{l}{h_1}$ values than for large $\frac{l}{h_1}$ values. The critical loads are plotted in terms of $\frac{P}{P_E}$ for columns in Fig 13 and it can be seen that for frames with the same section for the columns, a change in the inertia of the rafters results in a more significant change in the

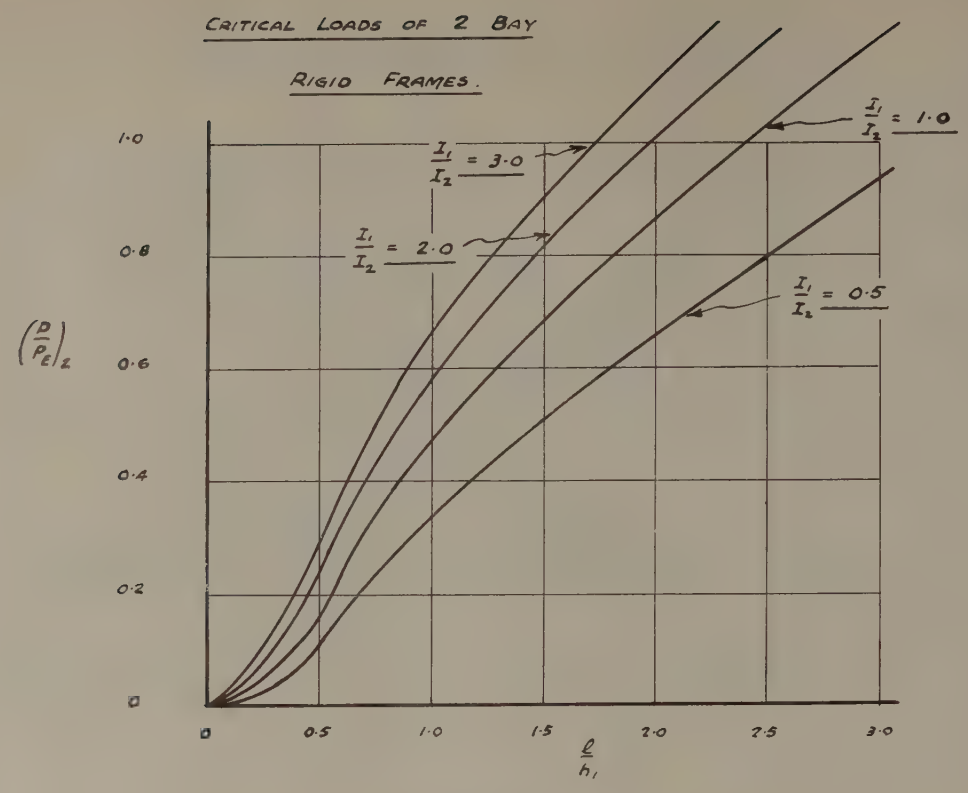

CRITICAL LOADS OF 2 BAY
RIGID FRAMES.
$\frac{I_1}{I_2} = 1.0$
$\frac{I_1}{I_2} = 3.0$
$\frac{I_1}{I_2} = 2.0$
$\frac{I_1}{I_2} = 0.5$
$\left(\frac{P}{P_E}\right)_2$
1.0
0.8
0.6
0.4
0.2
0
0.5
1.0
1.5
2.0
2.5
3.0
$\frac{\ell}{h_1}$

Fig. 12.

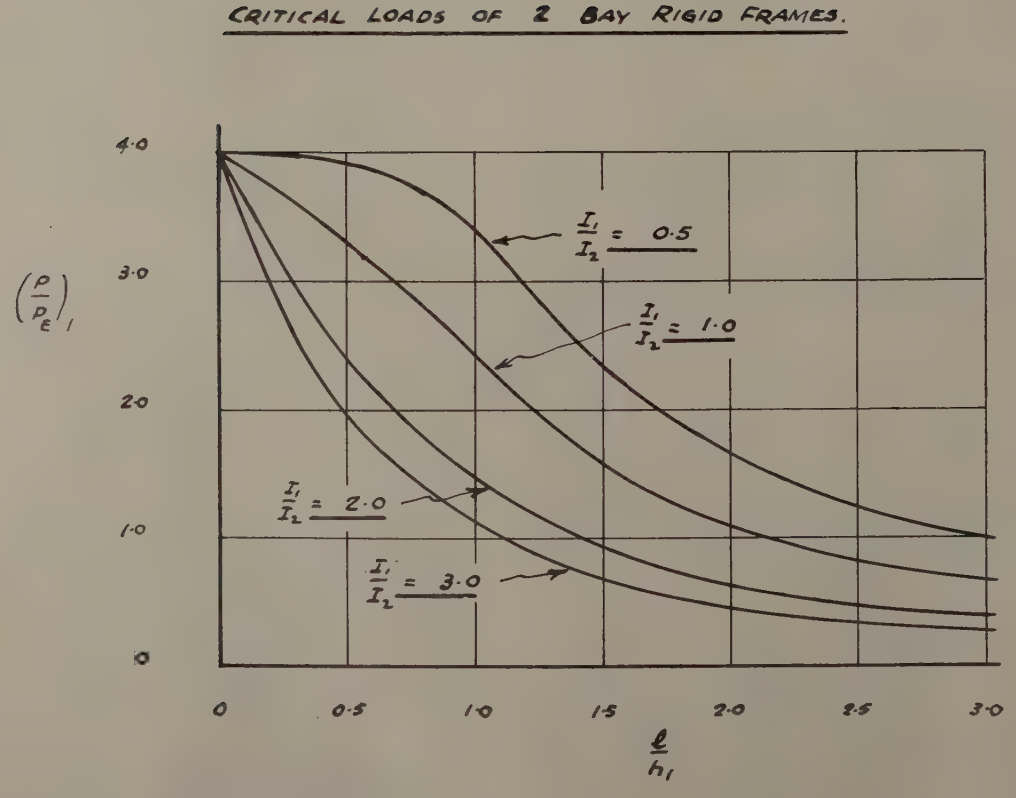

CRITICAL LOADS OF 2 BAY RIGID FRAMES.
$\frac{I_1}{I_2} = 0.5$
$\frac{I_1}{I_2} = 1.0$
$\frac{I_1}{I_2} = 2.0$
$\frac{I_1}{I_2} = 3.0$
$\left(\frac{P}{P_E}\right)_1$
4.0
3.0
2.0
1.0
0
0
0.5
1.0
1.5
2.0
2.5
3.0
$\frac{\ell}{h_1}$

Fig. 13.

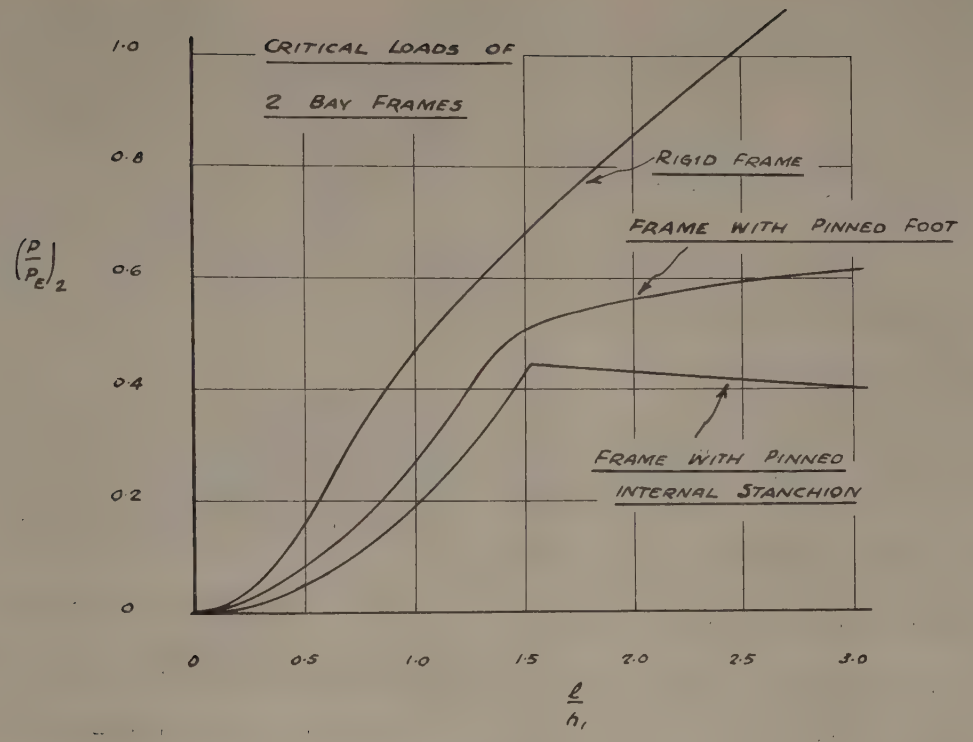


Fig. 14.

CRITICAL LOADS OF 2 BAY FRAMES

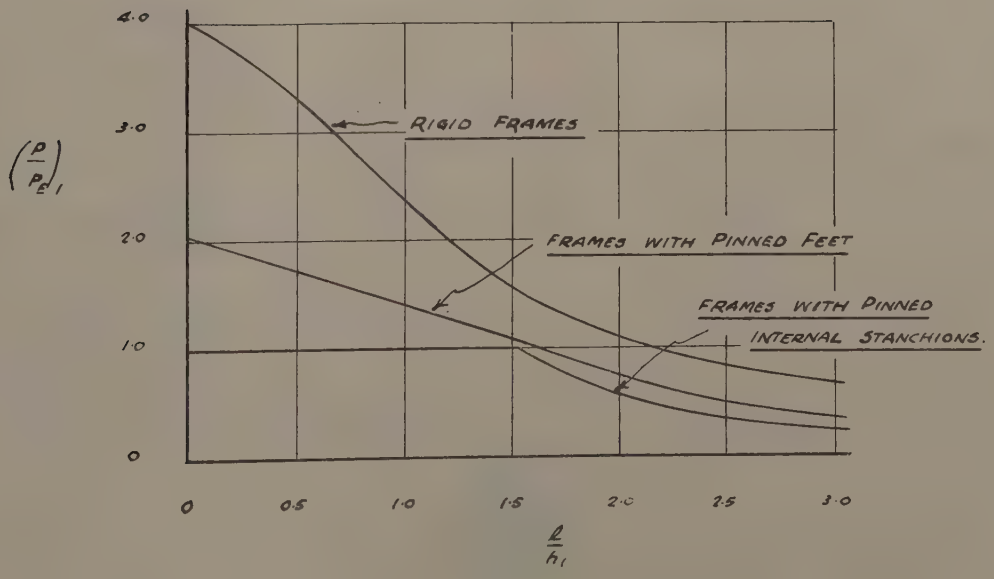


Fig. 15.

critical load for large values of $\frac{l}{h_1}$ than for small values of $\frac{l}{h_1}$. For the reason given previously no attempt will be made here to compare the relative efficiencies of frames with different ratios of inertia.

Series C

Two bay frames with Rafter Slope $22\frac{1}{2}°$

Variables: $\frac{Span}{Stanchion\ height}$ *ratio, Internal Column Fixity*

In this series some of the results from Series A.1 and Series B.1 are combined with a set of results for the critical loads of frames with internal stanchions rigidly fixed at the top and pinned at the bottom and having $\frac{l}{h_1}$ values varying from 0 to 3·0. The critical loads are plotted in terms of $\frac{P}{P_E}$ for the rafters in Fig. 14 and in terms of $\frac{P}{P_E}$ for the columns in Fig. 15 The advantage to be won by the use of rigid internal stanchions is apparent. It is of course more marked for frames with small $\frac{l}{h_1}$ values where the critical loads are largely dependent upon the local column buckling mode.

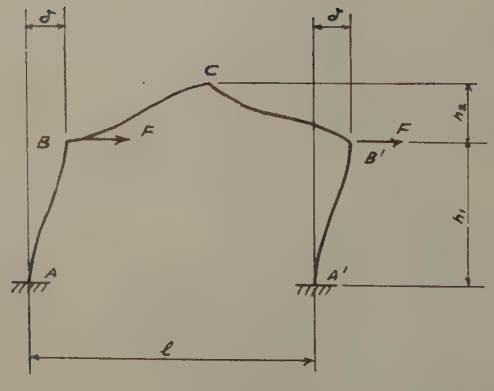


Fig. 16.—Rigid frame with infinite number of bays.

Conclusions

In summarising the conclusions from these computer results, it must be remembered as previously mentioned that the elastic critical load is only one of the parameters determining the failure loads of structural frameworks. However it may be valuable to state some general trends.

(1) Critical loads reduce for increasing number of bays. There is a lower limit for continuous frames but for frames with pinned internal columns the lower limit is zero.

(2) Critical loads reduce with increasing value of $\frac{l}{h_1}$, the reduction being greater for frames with pinned internal columns.

(3) For frames with constant section the critical loads are largest when the slope of the rafters is approximately $22\frac{1}{2}°$ for frames with pinned internal columns and approximately 30° for rigid frames.

(4) For frames with large $\frac{l}{h_1}$ value, a significant increase in the critical load can be obtained by increasing the inertia of the rafters.

For frames with small $\frac{l}{h_1}$ value, a significant increase in the critical load can be obtained by increasing the inertia of the columns.

(5) A considerable increase in the critical load is obtained by using rigid internal stanchions but the increase reduces with increasing $\frac{l}{h_1}$ value.

In addition to the above conclusions the results give extremely interesting examples of the shapes of some frame stiffness curves and also of the transition from one type of buckling mode to another.

The author wishes to thank Dr. R. K. Livesley for the use of his stability programme.

This work has been carried out in the Department of Structural Engineering at the College of Science and Technology, Manchester.

References

1 Livesley, R. K. and Charlton, T. M. "The use of a Digital Computer with particular reference to the Analysis of Structures." Trans. *North East Coast Institution of Engineers and Shipbuilders*. November 1954.

2 Livesley, R. K. "The Application of an Electronic Digital Computer to some Problems of Structural Analysis." *Structural Engineer*. January 1956.

3 Merchant, W. "A Connection between Rayleigh's Method and Stiffness Methods of Determining Critical Loads." *IX International Congress of Applied Mechanics*—Brussels, 1956.

4 Lundquist, E. E. "Principles of Moment Distribution Applied to Stability of Structural Members." *5th International Congress of Applied Mechanics*. Cambridge 1952.

5 Chandler, D. B. Ph. D. Thesis Manchester University 1955.

6 Livesley, R. K. "Tables of Stiffness and Carry-Over Factors for Structural Members under Axial Load." Manchester University Press.

Appendix

Critical load of Frame with Infinite Number of Bays (see Fig. 16).

	A	*B*		*C*		F_B
Rotation of C, C¹ etc.		$c_2\ s_2\ k_2\ \theta_C$	$c_2\ s_2\ k_2\ \theta_C$	$s_2\ k_2\ \theta_C$	$s_2\ k_2\ \theta_C$	
Rotation of B, B¹ etc.	$c_1\ s_1\ k_1\ \theta_B$	$s_2\ k_2\ \theta_B$	$s_1\ k_1\ \theta_B$	$s_2\ k_2\ 0_B$	$c_2 s_2 k_2\ 0_B$ $c_2 s_2 k_2\ \theta_B$	$-\frac{s_1 k_1(1+c_1)}{h_1}\ 0_B$
Sway	$-\frac{s_1(1+c_1)k_1\delta}{h_1}$		$-\frac{s_1(1+c_1)k_1\delta}{h_1}$			$\frac{2s_1(1+c_1)k_1}{m_1 h_1^2}\ \delta$

$$F_C = -\frac{(M_{BC}+M_{CB})\,2}{h_2}$$

$$F_B = \frac{(M_{BC}+M_{CB})\,2}{h_2} - \frac{(M_{AB}+M_{BA})}{h_1} + F_C$$

$$= -\frac{M_{AB}+M_{BA}}{h_1}$$

C is in equilibrium : $2\,s_2k_2\,(\theta_C + c_2\,\theta_B) = 0$

$$\theta_C = -\,c_2\,\theta_B$$

B is in equilibrium :

$$2\,s_2k_2\,(\theta_B + c_2\,\theta_C) + s_1k_1\,\theta_B - \frac{s_1\,(1+c_1)\,k_1\,\delta}{h_1} = 0$$

$$2\,s_2k_2(\theta_B - c_2^{\,2}\,\theta_B) + s_1k_1\theta_B = \frac{s_1(1+c_1)\,k_1\,\delta}{h_1}$$

$$\theta_B = \frac{s_1(1+c_1)\,k_1}{h_1\,\{2\,s_2k_2(1-c_2^{\,2}) + s_1k_1\,\}}\,\delta$$

$$F = \left[-\frac{s_1k_1(1+c_1)}{h_1}\ \frac{s_1k_1\,(1+c_1)}{h_1\,\{2s_2k_2\,(1-c_2^{\,2}) + s_1k_1\,\}} + \frac{2s_1\,(1+c_1)\,k_1}{m_1h_1^{\,2}}\right]\delta$$

$$-\frac{s_1k_1(1+c_1)}{m_1h_1^{\,2}}\left[\frac{m_1s_1k_1(1+c_1)}{2\,s_2k_2(1-c_2^{\,2}) + s_1\,k_1} - 2\right]\delta$$

$$= \frac{s_1k_1(1+c_1)}{m_1h_1^{\,2}\,\{\,2\,s_2k_2(1-c_2^{\,2}) + s_1k_1\}}\left[\,m_1s_1k_1(1+c_1) - 4\,s_2k_2(1-c_2^{\,2}) - 2s_1k_1\right]\delta$$

$$= f\,(skc)\left[s_1k_1\{\,m_1\,(1+c_1) - 2\,\} - 4s_2k_2\,(1-c_2^{\,2})\right]\delta$$

$$F = K\delta$$

$$K = s_1k_1\,\{m_1\,(1+c_1) - 2\} - 4\,s_2k_2\,(1-c_2^{\,2})$$

Critical Condition is :

$$s_1k_1\,\{\,m_1\,(1+c_1) - 2\,\} - 4\,s_2k_2\,(1-c_2^{\,2}) = 0$$

$$s_1\,\{\,m_1\,(1+c_1) - 2\,\} - 4\,s_2\,(1-c_2^{\,2})\,\frac{k_2}{k_1} = 0$$

Research for the Concrete Industry *

The Work of the Research Organization of the Cement and Concrete Association

By

A. R. Collins, M.B.E., D.Sc., M.I.Struct.E., M.I.C.E. (Member of Council)

1. Introduction

Though the 'concrete industry' has no distinct entity except in certain specialized aspects, the term is a useful one in describing those parts of the work of various professions and industries that involve the use of Portland cement. It is also appropriate for the purpose of this paper in that the research organization of the Cement and Concrete Association, though financed by the cement manufacturing industry, is in fact concerned almost entirely with providing help to the cement user.

It would be impossible in one paper to give a complete description of more than ten years' work of a research team of over one hundred people; research that on major projects alone is represented by over 3,000 pages of formal reports. An attempt will, however, be made to give a general picture of the functions and activities of the organization with examples of what has been done.

In the last fifty years research has emerged from the back room into the front parlour; it has grown from a minor activity of a few scientists to a major instrument of international politics. In this paper we are, however, not concerned with research for political ends, but with research in the service of a specific and restricted technology. The main, even the only, objective of industrial research is to improve and if possible cheapen the product of the industry it serves. Industries, however, vary and the research they undertake differs greatly. Some were born in the laboratory and depend for development on large-scale research to which they devote a significant proportion of their turnover. Some, though well developed before the advent of organized research, have adopted it with remarkable results. Others have, as it were, had research thrust upon them. The concrete industry may well be placed in the last category, not because those concerned with construction have been unduly backward but rather because the construction industry already had a history of many thousands of years of field experimentation with techniques very different from those of the research laboratory. To the practitioner in the construction field research appeared as a rather alien discipline for which the industry as a whole was not trained. To this could be added the reason that the industry consists of many individuals and small firms difficult to organize into a body capable of supporting research. It is therefore not surprising that most research in concrete is undertaken by the universities, governments and the material-supplying industries.

* *Paper to be read before the Institution of Structural Engineers at 11, Upper Belgrave Street, London, S.W.1., on Thursday, 24th March, 1960, at 6 p.m.*

The Portland cement manufacturing industry is basically chemical in nature and it is only natural that it should be more ready to undertake research than the cement user. However, cement accounts for only a small part of the total cost of concrete and the expense of providing all the resources necessary for adequate research in all phases of concrete usage would be disproportionate to the cost of cement. The resources available are nevertheless substantial, but they do become somewhat extended in attempting to do research, provide advice and educate an industry with a turnover of some £500 m. a year. Because of this the methods used have to be planned, not so much to help industry directly but rather to help industry help itself. This requires close co-operation with industry in all aspects of the work and close integration of research and other activities. The research undertaken by the Cement and Concrete Association is for example planned with the help of engineers, architects and all branches of the concrete industry; many research projects are undertaken with the co-operation of and, sometimes, at the request of, an engineer or some specialised group, visitors are welcomed at the Research Station and an advisory service is conducted to assist in design and construction. A considerable amount of educational work is also undertaken, mainly through residential training courses at the Research Station but also in co-operation with learned societies, universities, technical colleges, individual firms and specialized parts of the industry. All this provides a two-way multi-channel system of communication through which the results of research can be quickly passed to the user and through which modifications to research projects take place continuously and almost unconsciously. The training courses are particularly useful in providing close contacts and in presenting to the research worker audiences that might not be available through the medium of published reports.

The integration of research with these other activities is obtained chiefly through the research staff being engaged in them. This naturally tends to interrupt the research work itself and requires careful control, but, in general, the advantages gained in communication and in service to the industry outweigh the disadvantages.

The nature of research is the same irrespective of the field it serves. The word itself implies looking again, the questioning of accepted ideas, the repeated experiment, but in addition to this, research requires the elimination as far as possible of extraneous and human elements in its results. It consists essentially in allowing Nature to provide the answer we require, but though Nature's answers are always truthful they are also literal and it is not always possible for us to understand them unless the question itself was

a simple one. The art of research lies mainly in the framing of questions in the form of controlled experiments (unaffected by unknown variables), experiments that produce answers we can understand.

Within this universal pattern the techniques and methods of research vary very widely even in one comparatively specialized industry. Most work can, however, be classified as fundamental research on the laws of nature and properties of matter, basic research on the nature of specific materials or of technological processes, applied research on the properties of materials and use of processes and, finally, the collection of data through testing. Many industrial research organizations also undertake a varying proportion of development work.

Fundamental research is seldom undertaken by industry and is generally the responsibility of the University or research institute. From it come the major developments that have revolutionized industry.

Basic research on the nature of materials and processes is a proper function of industry, but is naturally undertaken to a varying extent in different fields. In some industries it is the subject of considerable effort and much of this is of a speculative nature undertaken in the expectation that the small successful part will more than pay for the unsuccessful remainder. Basic research of a less speculative nature is also undertaken to provide background knowledge of the materials and processes used in industry. It has several merits. From it alone can come a proper understanding of the problems of industry and this understanding is a fertile source of new concepts. The results also have permanent value. They are unaffected by changes in industrial techniques and the understanding they provide can be used to predict the behaviour of materials and processes in untried conditions. A further merit of basic research is that in the engineering field especially it provides a link with the fundamental sciences and speeds the bringing of new scientific knowledge to applied research and thence to practice.

Basic research cannot, however, be more than a part of industrial research. The main resources must be devoted to applied research to provide the technological information on which improvements in existing materials and processes can be based. The results of applied research are generally of immediate usefulness but they are also often of passing value, for they are relevant only to the materials and conditions that apply at the time and a change in practice may make them obsolete. Applied research may therefore need to be repeated in different places to allow for varying conditions and at different times to allow for the changes that it itself may have brought about.

Applied research is naturally the field in which research-worker-practitioner co-operation is most desirable and most fruitful. Apart from direct assistance on each side the interchange of information and ideas reduces unnecessary work and ensures the application of results. Some applied research can be or may best be carried out in the field, and the practising engineer might well accept a greater degree of responsibility for it than has been common in the past.

In addition to the work that can truly be called research there is always a need for experimental data obtained both in the laboratory and in the field. The data may be required as an aid to research itself, as an aid to the application of results or for the purposes of specification or design. The collection of data forms an essential part of the functions of any research station, but like the advisory and similar work it has to be controlled, for it always tends to replace the ultimately more useful but long-term research work.

Unless resources are very large or its interests very limited a research organization in the construction field cannot alone develop important new materials, plant or processes. In co-operation with industry it can, however, produce valuable developments. Through tests on existing materials and processes it can determine where improvements are required, it can provide data for the design of plant, measure performance and use its background knowledge in suggesting possible lines of attack. The main effort in new development should, however, come from industry, for in producing this effort industry accepts a stake in the success of the work and provides the conditions needed for its rapid adoption in practice.

The work of the Research Station of the Cement and Concrete Association complies quite closely with this general pattern. Its organization is based very largely on co-operation with the practising engineer and architect and with those concerned with construction. The different kinds of work undertaken and the different types of help provided by practice, however, preclude the development of any neat universal pattern of co-operation. The methods used vary from department to department, from project to project and with the individuals involved on both sides.

2. The Research Station and Organization

The research station of the Association was started at the end of 1946 in the house and grounds of Wexham Springs near Fulmer, Buckinghamshire. At that time restrictions on new buildings made it necessary to accommodate laboratories in the house and outbuildings and further development was necessarily rather slow. In 1952, however, it became possible to construct a structures laboratory, the first specially designed building, and since then a policy of new building to house efficiently all the work of the station has been followed. Buildings so far constructed include, in addition to the structures laboratory, a chemistry and physics laboratory, a building for experimental construction and demonstrations, and one containing the facilities for training courses, canteen and printing department. Two buildings to house the concrete laboratory, the roads department, laboratories for precast concrete and aggregates, workshops and stores will be begun in 1960.

The research programme and progress is reviewed by a Research Advisory Committee, the members of which cover a wide range of interests, and the work of the structures department is, in addition, discussed by a Structures Research Committee composed chiefly of consulting engineers. Through the discussions of these committees and through the advisory and training activities of the Association already mentioned, the research programme is modified as required.

Unless it has almost unlimited resources a research organization cannot simultaneously undertake work on all possible problems. On the other hand, in order to provide an effective advisory and educational service it is necessary to employ experts specializing to some extent. One of the most effective ways of producing expert specialists is through research and it is, therefore, necessary to operate in each of a certain minimum number of fields in order to support the advisory and educational work. At Wexham Springs, in addition to the administration, there are separate departments dealing respectively with chemistry and physics, concrete materials and proper-

ties, structures, roads and works and services. Each is composed of from three to five graduate research workers with about ten laboratory technicians and other assistants. The Works and Services Department is responsible for maintenance and experimental construction as well as research on practical problems, and contains a team of about forty craftsmen and other workers.

As an example of one of the methods of co-operation with industry it might be mentioned that in addition to its own research departments the Association provides laboratory space and general services for research teams employed respectively by the Research Committee for the Cast Stone and Cast Concrete Products Industry and by the Sand and Gravel Association of Great Britain.

3. The Work of the Research Station

(a) The Chemistry and Physics of Concrete

Though the work of the Chemistry and Physics Department is on the whole more basic than that of the others it does in fact contain examples of all the functions already mentioned. In the field of basic research it studies the chemical and physical changes that take place during the hydration of Portland cement, it does applied research on durability and certain practical problems, it determines the chemical and physical properties of materials, performs routine chemical analysis and provides a service to the engineering departments and to industry, especially in the determination of the causes of deterioration of materials.

An account of the basic research is perhaps more appropriate to a chemical paper, but as this work depends greatly on the development of experimental technique, and as the technique has some direct bearing on practice, it may be of interest to include a brief description of some of the methods used.

Because Portland cement is made by a comparatively simple process from common unrefined, though carefully selected, natural minerals of complicated and varied composition, its chemical nature and properties are by no means simple. It is essentially a silicate mineral and silicon has the ability of forming different compounds of similar and even the same composition. The result is that the classical methods of chemical analysis that give the elemental composition of any material do not provide much information of value to the cement chemist, though they are valuable in works quality control. Before the war, the methods of mineralogy using the optical microsope provided the chief means of identifying the various compounds present in cement, but in recent years X-ray crystallography has been increasingly used.

Every crystalline substance has the molecules of which it is composed arranged in a characteristic three-dimensional pattern. Visible light is quite unable to resolve this pattern, for its wavelength is too great compared with the spacing of the molecules. If, however, a narrow beam of X-rays is projected through the crystal it will be diffracted in a manner depending on the pattern of the molecules. A strip of photographic film placed round the crystal will, on development, provide an indication of the way the diffractions have occurred. With a mixture of different crystals in the beam the record will indicate the proportions of each compound present.

The use of a photographic record is, however, not very precise, and an alternative method has been evolved for determining the diffraction pattern directly

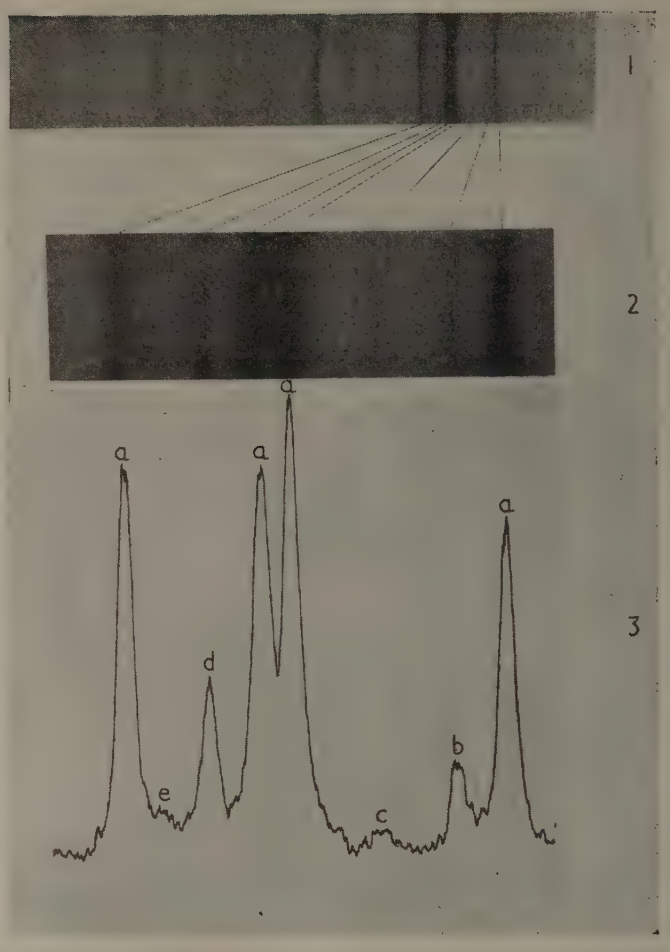


Fig. 1.—X-ray analysis records for a typical Portland cement. (1) Photographic record. (2) Enlargement. (3) Diffractometer record. (a) Peaks due to alite (the tri-calcium silicate compound) plus di-calcium silicate: (b) alite alone: (c) di-calcium silicate alone: (d) tri-calcium aluminate: (e) the lime-alumina-iron compound.

and more quickly. It consists of replacing the photographic paper by a Geiger counter that moves round the material subjected to the X-ray beam and records automatically on a moving strip of paper the radiation received in each position. This produces directly a graph in which peaks represent the intensity of the diffracted ray. Each compound has its characteristic peak in a definite position, and from the height of the peak the proportion of the compound present in the sample can be calculated. A typical photographic X-ray diffraction record and an equivalent Geiger counter diffractometer-graph are shown in Fig. 1. A photograph of the diffractometer is shown in Fig. 2.

Note: the caption to Fig. 1 will explain the record.

Closely allied to research on the composition and hydration of cement is the problem of the deterioration of concrete under attack from natural and chemical agents. Among the most common of the natural aggressive agents are the sulphates. The chemical composition of a cement, as determined by X-ray analysis, may well give a good indication of its probable resistance to sulphate attack, but it is nevertheless desirable to have a direct test. Tests on large samples of concrete are not entirely satisfactory because of the many years of exposure necessary to produce

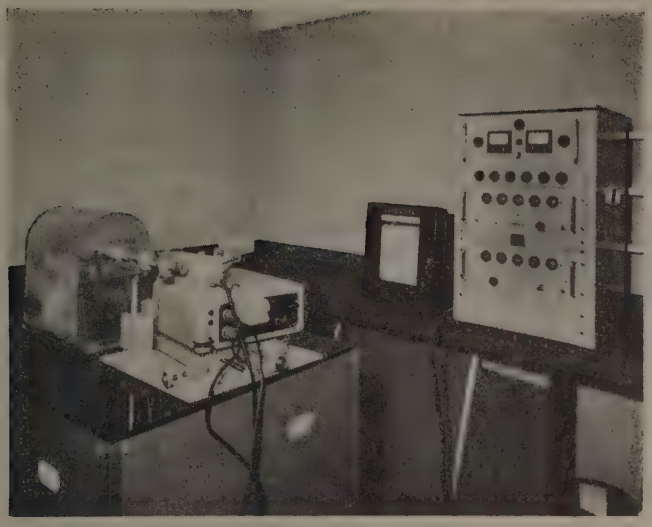


Fig. 2.—X-ray diffractometer apparatus. The X-ray tube projects from the plastic cover and the moving Geiger counter is in the centre background.

a significant effect. Research is therefore currently in progress to assess the value of very small test specimens for this purpose. Small test cubes have often been used in the past for testing other properties such as the strength of cements, but the method has not been well exploited. The strength of a cement-mortar cube of, say, ½ in. side, is very rapidly affected by a corrosive environment, and since large numbers of small specimens can be made and tested easily and quickly, multiple repetitions of tests can be used to offset any greater variability of test results that arises from the use of very small specimens.

The results obtained so far with ½ in. cubes show that the method rapidly gives a good indication of sulphate resistance, but it cannot yet be claimed to be sufficiently reliable to be a standard accelerated test. In any event the results must, as with any accelerated test, be related to full-scale exposure.

Another application of the small-specimen technique is concerned with the effect of gamma radiation and neutron bombardment on concrete. The need for this research arises from the increasing use of concrete in the containment vessels and biological shields of nuclear reactors. Existing experimental reactors have little space for large specimens and it is necessary to use small specimens in irradiation tests. The previous experience with ½ in. cubes has therefore been particularly useful in this work, and in co-operation with the Building Research Station and the Atomic Energy Research Establishment samples of concrete are being exposed in atomic piles and measurements made of any changes in their properties. The tests have not yet been in operation long enough for any conclusions to be drawn.

(*b*) *Mix design and the engineering properties of concrete*

Although he recognizes the importance of the chemical behaviour of concrete, the engineer is naturally more concerned with the engineering properties such as strength, workability, creep and shrinkage for these directly affect his design and methods of construction and are to a large extent within his control.

This is a field that is particularly difficult and unrewarding to attack through basic research. There is, for example, no satisfactory method of measuring the important properties of the aggregates. Grading curves are a reasonably accurate means of representing particle size distribution but particle shape and surface texture are still largely a matter of subjective estimation. It has been thought that the specific surface of an aggregate of known size might be used as a combined measure of shape and texture and an apparatus has been devised in an attempt to measure this parameter. The method involves measuring the loss of head and rate of flow of a liquid passing through a bed of aggregate particles under conditions of streamline flow. The aggregate is placed in a large diameter tube and a suitable liquid is pumped through it at a constant rate, the loss of head being measured by the normal type of manometer.

Measurements of specific surface of several aggregates were made and the values related to the workability of mixes of concrete made with them. The results showed that workability was related to specific surface only for mixes that would be regarded as being over-sanded. Normal mixes have shown no apparent relation and it may be that while specific surface as measured in the test is an important factor in determining the effect of fine aggregate, it does not represent the important properties of coarse aggregate.

The empirical approach to mix design has been much more successful than any based on a fundamental or theoretical approach and all the procedures at present in use employ tables or curves representing experimental data. The method most commonly employed in Britain is that developed at the Road Research Laboratory but this is restricted to aggregates of ¾in. and 1½in. maximum size. Work of a similar nature done by the Association has extended these data to ⅜in. aggregates and a further extension has been made for mixes required to produce concrete of higher strengths than those covered in the earlier work.

The need for this extension became clear as soon as prestressed concrete came into common use and work was, therefore, undertaken to determine the factors that are important in the production of high strengths. This work has been well reported elsewhere and little need be added here except to say that in concrete having a strength of 7,000 lb. per sq. in. or more both the aggregate and the workability play increasingly important roles and they both set limits on the strength obtainable. The limit set by the aggregate depends on the material of which it is composed and generally lies in the range from 12,000 to 15,000 lb. per sq. in. The limit set by the workability depends on the means available for compaction and operates in such a way that even when vibration is combined with pressure no further gain in strength can be obtained by making the mix richer than about 1 : 2.5 or 1 : 3 by weight. With workability and aggregate type playing important roles it follows that a desired strength cannot necessarily be obtained through a simple choice of water-cement ratio as is done for normal mixes. It is necessary to make this choice in relation to the aggregate and workability to be used.

A mix design procedure allowing for these factors has been developed and published. With it, and using possible methods of compaction, mixes can be designed to give average strengths of 8,000 to 10,000 lb. per sq. in. at 28 days and up to 3,000 lb. per sq. in. at 24 hours, both with ordinary Portland cement and normal wet curing. (See Fig. 3). The work has also shown that it becomes virtually impossible to reach strengths of a much higher order without the use of economically impracticable methods of compaction.

Whatever level of strength is required, the process of mix design is always closely bound with that of quality control on the site and in designing a mix to satisfy a strength specification an assessment has to be made of the average strength that has to be aimed at in order to satisfy the minimum strength requirement.

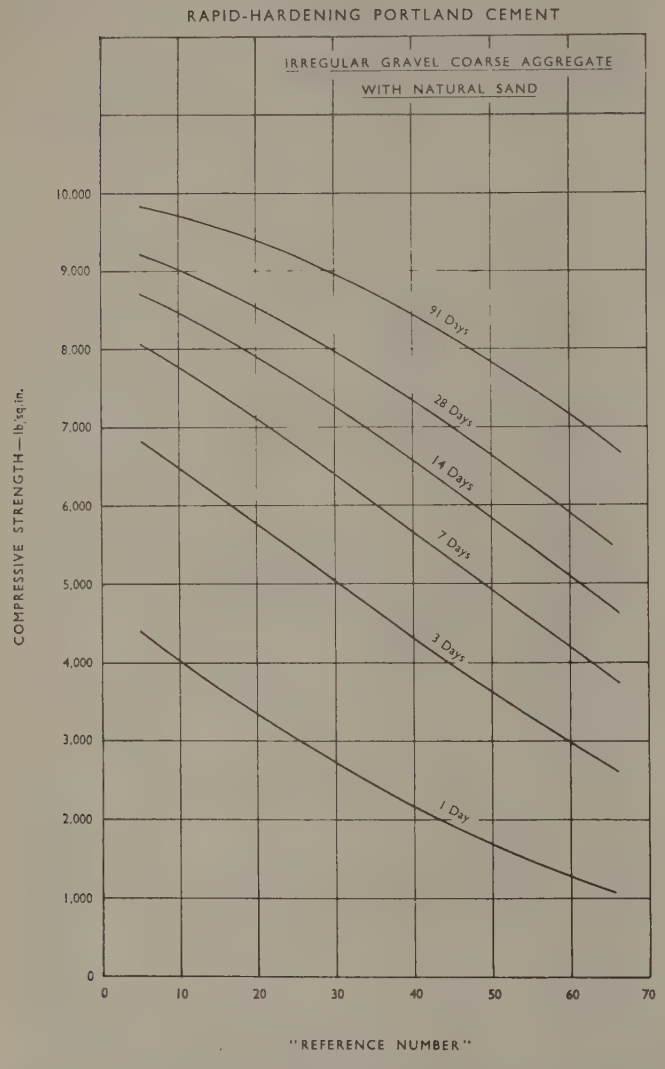


Fig. 3.—Typical diagram for designing high-strength concrete. The "reference number" is a parameter based on water-cement ratio, workability and size of aggregate. Reference number 20 is equivalent to a water-cement ratio of 0·34 with very low workability, and No. 60 to a water-cement ratio of 0·49 with medium workability, both for $\frac{3}{4}$ in. aggregate.

Differing assumptions have been made about the form of the relationship between these two strengths; one, for example, is that the minimum strength should be taken as a constant arithmetical proportion of the average strength, and another is that the two strengths differ by a fixed amount. An analysis was, therefore, carried out on some 100,000 cube results obtained from about 300 construction sites, where concrete of varying strength levels was produced under different standards of control. The result indicated that the mean and minimum strengths obtained were, in fact, not related in a simple way but that the water-cement ratios required to give these values of strength were directly proportional for any one standard of control. The conclusion was, therefore, that the best mix design procedure should be, not to estimate an average strength required to give the specified minimum strength and then design the mix accordingly, but to choose the water-cement ratio needed to give the specified minimum strength, reduce it by a factor depending on the degree of control and design the mix for this new water-cement ratio. Other conclusions were that the degree of supervision on the site had a much more important effect than the type of equipment employed, and that the normal methods of weighbatching were subject to appreciable error which was considerably reduced by servo-operation of the batching plant.

Although much has been written on the subject of the variability of concrete a number of misconceptions still remain as a result of a tendency to assume that the total variability of the final product can be assessed by arithmetical summation of the variations resulting from each cause rather than by the correct method of taking the square root of a sum of the squares. Laboratory research in this field cannot well be described except in detailed statistical terms which space does not permit. However, it can be said that the overall variability of field concrete can be expected to be less than that of the test cubes and that this in turn is affected to a lesser proportion by variations in the materials than was previously supposed. In particular, any variation in the standard test strengths of the cement used has been found to have a smaller effect on the strength of concrete than would be expected, and its effect on ultimate quality is even less.

The compressive strength is often taken as the criterion of the quality of the concrete in the hardened state, but other properties are frequently of equal or greater importance. In road work, for example, the flexural strength is of considerable interest and it is often advocated that such concrete should be air-entrained. Tests have, therefore, been made to compare the compressive and flexural strengths, after curing in water or air, of concretes of similar cement content and workability with and without entrained air. Other properties measured were bulk density, ultrasonic pulse velocity, dynamic modulus of elasticity, and change in weight during curing.

Although, in general, the compressive and flexural strengths of the air-entrained concrete were less than those of the plain concrete, the difference in flexural strength of air-dry specimens was negligible. Air-entrained concretes would appear to be less susceptible to the dangers resulting from a lack of artificial curing than plain concretes because the changes in weight during curing and the changes in compressive and flexural strengths due to differences in curing were less for the air-entrained specimens.

Many of the difficulties of using concrete arise from the fact that it is susceptible to volume changes during hydration and to variations in temperature and humidity. This is a vast field for basic research which it is planned to explore more fully when the resources of the new laboratory mentioned in Part 2 are available. However, a start has been made on the measurement of the shrinkage characteristics of fresh concrete, from 10 to 15 minutes after mixing up to two or more days. The specimen of concrete consists of a small horizontal prism placed in a mould designed to reduce surface restraint to the minimum. In this specimen are placed two small paddles which form a part of a

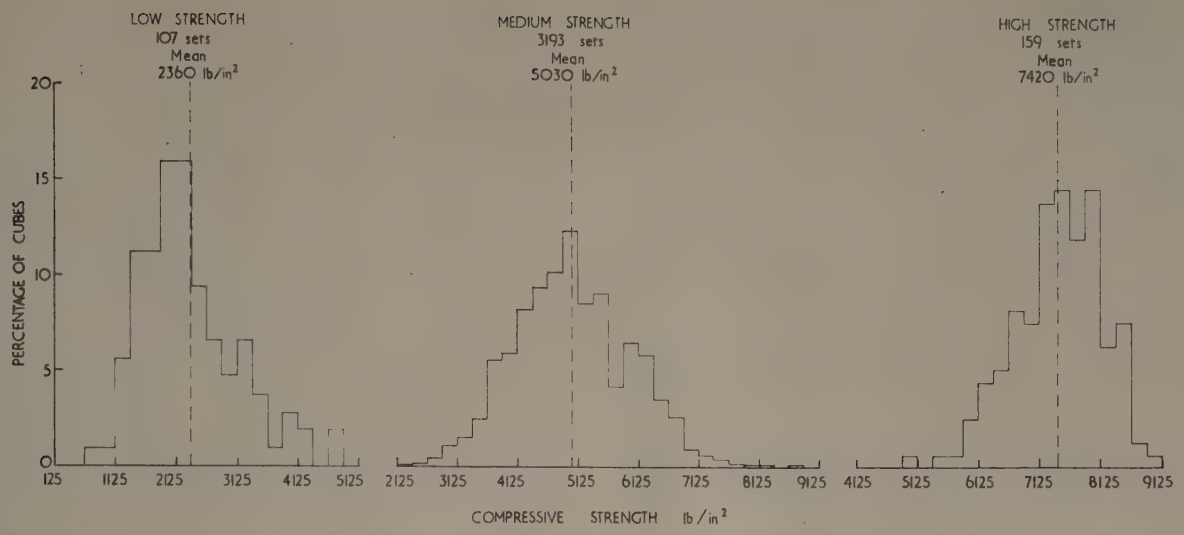


Fig. 4.—Cube-strength histograms for concrete of low, medium and high strength, all made with good field control, showing skew distribution normally found with concrete of low and high strength.

mirror extensometer recording automatically by means of a beam of light reflected on to a rotating drum of photographic paper (see Fig. 5). It was found that under drying conditions apparent expansion of the concrete, thought to be primarily settlement, occurs immediately after placing up to a time between one and a half and four and a half hours after mixing ;

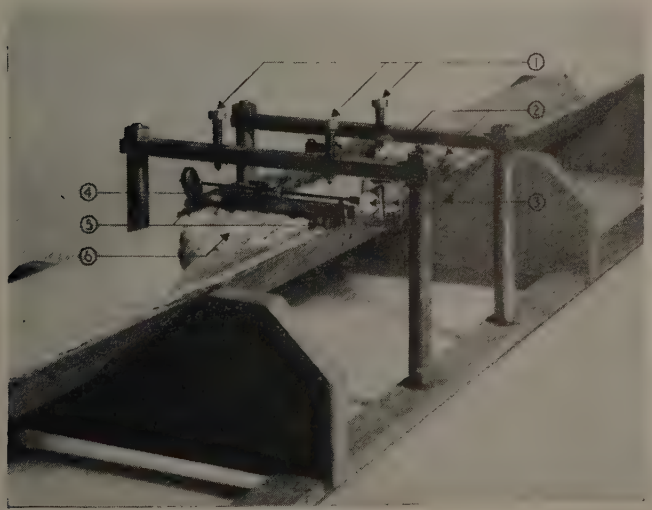


Fig. 5.—Apparatus for tests on early shrinkage of concrete. (1) Fixing screws. (2) Paddles. (3) Mirrors. (4) Roller. (5) Locating ball bearing. (6) Concrete.

by this time the concrete has stiffened sufficiently not to flow. Shrinkage, varying between 1×10^{-4} and 13×10^{-4} per unit length takes place during the next six to eight hours ; there is then little further movement for several days. Concrete kept under water shows a greater initial apparent expansion, and no shrinkage.

For mixes of approximately constant workability, the amount of early shrinkage under drying conditions appears to increase as the richness of the mix increases (with corresponding changes in the water-cement ratio), and it also increases as the amount of bleeding within the concrete decreases.

(*c*) *Research on Roads*

In 1953 a Roads Department was added to the research organization to examine the problems of designing and building reinforced concrete, prestressed concrete, lean concrete and soil-cement roads, airfields and other paved areas.

The work of this department is a notable example of the co-operation of the research worker and practising engineer, for research on roads is often possible only when carried out on the full scale. Much of the research of the Roads Department is done in the field in co-operation with the Road Research Laboratory, the Ministry of Transport, with local authorities and contractors. Much also consists of combining theory and practice. For example, on the design of the road pavement, theoretical or model analyses are of limited value because the performance and life of the road depend so much on repetitions of loads and changes in temperature and moisture. Theoretical methods could be used to design a road, making allowance for all these factors, but this would involve the use of a factor of safety which would, in most cases, make the design quite uneconomical. Design recommendations for roads are, therefore, based partly on theory, partly on an examination of the condition of old roads and partly on the results obtained from full-scale experimental roads.

In 1955, design recommendations for reinforced concrete roads were affected by a desire to place joints as far apart as possible due to their adverse effect on riding quality. In 1956, a method of sawing joints in the hardened concrete was introduced into this country and a considerable amount of development work was undertaken at the Research Station with the result that closely-spaced joints ceased to

be objectionable (see Fig. 6). A study of the weight of reinforcement required in concrete road slabs in relation to joint spacing showed that considerable economy in the cost of the road was possible, amounting to between £5,000 and £10,000 per mile for a motorway, by decreasing the joint spacing and consequently the weight of steel. This work led to a revision of design recommendations in 1957.

Many of the problems in road work concern methods of construction and here again close co-operation between research and practice is necessary. The Association owns a train of concrete laying and joint forming machines on which a considerable amount of work was done to investigate the problem of riding quality. Some of the results of this work have since been put into practice on full-scale road construction and, more recently, have contributed to the modification of existing machines and to the development of new finishing machines producing much improved riding qualities.

Fig. 6.—Concrete road joint saw developed by the manufacturers in co-operation with the Research Station.

However, of the new roads built each year, by far the largest proportion is still in lengths too short to justify the use of large spreading and finishing equipment. Hand-held vibrating beams are commonly used for compacting and finishing these road slabs and it has been found that some skill is required in using them in order to produce a satisfactory surface regularity. After examination of the design of these beams and their vibration characteristics it was concluded that other means must be developed for giving final smooth riding finish. A suitable method of finishing was found in the U.S.A. where a device known as a scraping straightedge is commonly used. Several types of scraping straightedge were made and tested at the Research Station until one was found to suit conditions in this country. This device is now being manufactured and is rapidly coming into common use.

Lean concrete, lean mix or dry lean concrete, as it is variously called, with an aggregate-cement ratio of about 15 to 24 : 1 and with a workability suitable for compaction by rolling, is at the moment the most popular base material for roads in this country. Its use in practice has outstripped the research worker who, until recently, had little information on the mechanical properties of the material. At present lean concrete bases are usually designed as flexible pavements but frequently some allowance is made for the superior load-spreading characteristics of lean concrete over other base materials.

By compaction trials at the Research Station and by tests on construction sites a method of designing mixes suitable for this work has been developed, and a study of the strength and elastic properties of the material has been made. A graph showing some of the results obtained is given in Figure 7.

It will be seen that for any given cement content there is a water-cement ratio which just allows complete compaction to be obtained, and that if results for a number of different mixes are plotted as in the diagram the line joining the peaks of the curves obtained represents an optimum water-cement-ratio-strength curve for what is in fact a series of mixes of approximately constant workability. If for any mix, the water-cement ratio is higher than the minimum required for complete compaction, the strength falls below the optimum water-cement-ratio-strength curve. It follows from this that workability is in itself a factor in determining the strength of concrete.

This result is very similar to that obtained with the rich low-workability mixes used in the high-strength concrete investigation described earlier, and shows how basic research in different fields tends to coalesce and produce a general understanding of the overall properties of the material.

The research on the properties of lean concrete will form the basis of further work to develop a method of designing the thickness of lean concrete bases for various intensities of traffic and subgrade conditions. Tests have also been developed for site control over the production and compaction of the material.

Soil-cement is used primarily for road and airfield bases, but it has its place in the field of structures, for example, in foundations and as stable fill of high shear strength. Because of the great effect of the soil on the properties of the material it is essential to test each soil occurring on the site. Work has, therefore, been done on the development of simple testing methods and procedures which reduce to a minimum the amount of testing required to give the information required on mix proportions and compaction.

The use of the technique of detailed examination of the condition of existing roads has already been mentioned in connection with design procedure. With soil-cement bases failures have been extremely rare, but in the few examples that have occurred poor compaction has been found responsible for the trouble. A laboratory investigation into the causes of poor compaction has shown that this could be due to undue delay between mixing and compaction (see Fig. 8). With cohesive soils and gravels this delay can cause serious loss in strength but, curiously, not with sands.

Much interest has recently developed in another cement-stabilized road base material made from coarse and medium-grained granular soils and crushed rocks and very small proportions of cement. This can be regarded either as an extension of soil-cement or lean-mix concrete technique. Laboratory work is now in progress to develop a method of designing the mix

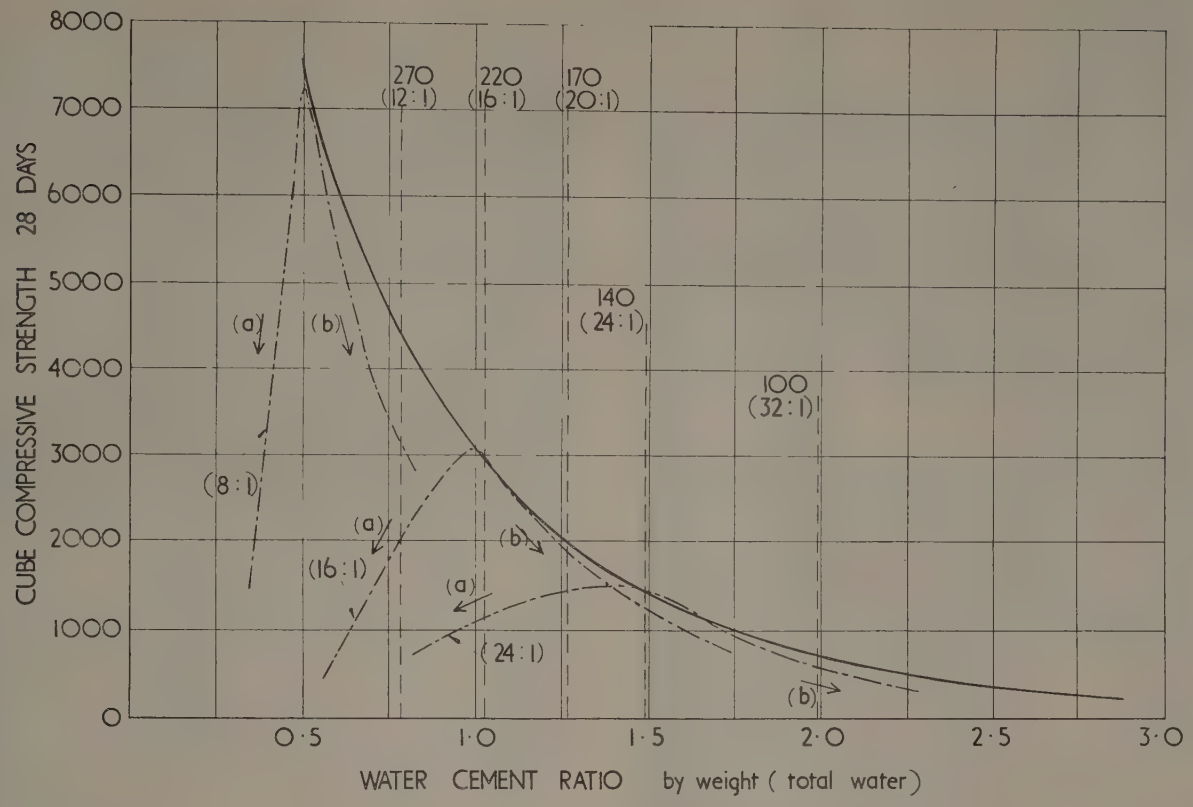


Fig. 7.—Diagram showing effect of mix proportions, water-cement ratio and incomplete compaction on the strength of lean concrete. The figures at the top of the vertical chain lines give cement content in lb. per cu. yd. and mix proportions by weight for concrete having a total water content of 6 per cent. (a) Decreasing workability, decreasing compaction. (b) Increasing workability, constant compaction.

proportions required for adequate stability and some progress has been made in relating the characteristics of these cement-bound granular materials to those of both lean concrete and soil-cement. It is quite possible that the distinctions between the three materials may eventually dissolve into a common technique.

(*d*) *Research in Structures*

Of all the research undertaken by the Association that done on structures is probably of the greatest interest in the present context. On the other hand, it is also probably the best known and in the limited space available attention will be devoted to no more than a few major items.

As in other fields, the work consists of basic research on the stress conditions in sections of reinforced and prestressed concrete, studies of the behaviour of certain types of structure made with a view to developing improved methods of design and tests on specific structural units or models of structures to determine the degree of agreement between design assumptions and actual behaviour.

In the field of basic research a series of tests has been initiated to investigate the problem of three-dimensional stresses in prestressed concrete. In the first series of tests, rectangular beams with a prestress typical of that used in practice were subjected to various combinations of bending and torsion ranging from pure bending to pure torsion (see Figs. 9 and 10). From these tests an interaction curve was obtained which showed that, generally speaking, in an ultimate load calculation it is perfectly justifiable to consider that bending and torsion hinges do not interact and that the strength of a bending hinge is not affected by a torsion hinge and vice-versa.

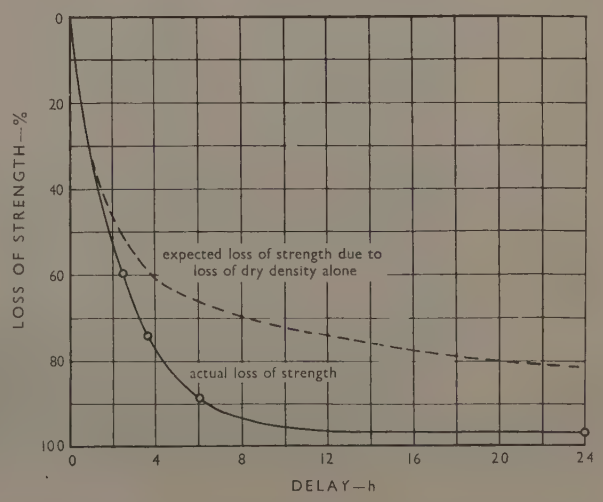


Fig. 8.—Diagram showing loss of strength in cement-stabilized brickearth related to delay in compaction.

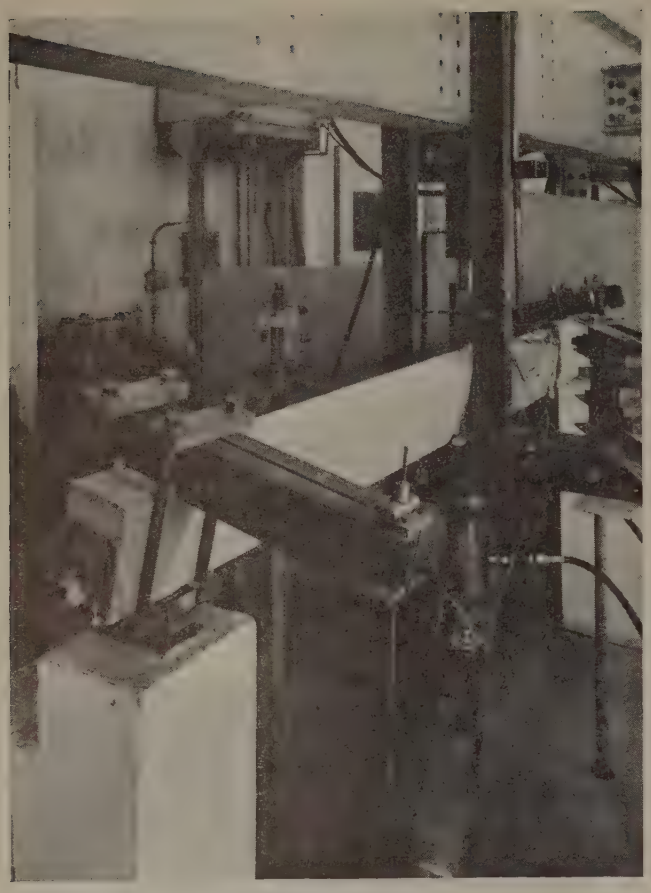


Fig. 9.—Test rig for experiments on combined torsion and bending stresses.

These experiments were continued with a series of tests on I-section beams where the interaction graph was shown to be virtually a straight line parallel to the bending axis, that is to say, there was no interaction whatsoever for loads up to about 85 per cent of the ultimate load.

The third series of tests is under way at the present time. This is concerned with T-beams in which the ratio of flange width to web depth is varied. These tests should complete this part of the programme which has been concerned solely with concrete subjected to a prestressing force followed by the action of bending and torsion. In the sections tested no mild steel in the form of stirrups was present and this particular problem will be considered in subsequent research.

A three-dimensional stress problem which arises very frequently in practice is that of the end blocks in prestressed concrete beams. Some theories were evolved by Magnel and Guyon, but these were of necessity two-dimensional approximations to a three-dimensional problem. A series of tests has, therefore, been carried out to obtain data upon which assessments of these theories and of possible other theories can be made.

In these tests prisms of rectangular section have been loaded with various concentrated loads. The ratio of the area of the loaded portion to the area of the cross section of the prism has been varied and the various proprietary anchorages have been incorporated in the prisms to investigate the effect that these of themselves introduce. One other factor that has been considered has been the size of the prestressing duct running through the prism. Initially, the specimens contained no additional mild steel reinforcement, but after the first series of tests mild steel reinforcement was incorporated. Observations were made of the distribution of stress in the surface of the concrete and from the data obtained it was possible to indicate for the various ratios of loaded area to cross sectional area the total tensile force present and the position of its centre of action. This should enable the amount of steel required to resist the force to be determined quite simply from either an empirical equation or a graph.

The work on simple prisms is to be extended to cover typical examples of end blocks as used in practice where, of course, a number of concentrated loads are present and the interaction one upon the other is required by the designer. It is hoped to study this problem not only by external strain measurements, but also with internal gauges so that a true distribution throughout the block can be obtained.

One of the major applied research projects is that concerned with the design of bridges subjected to the Ministry of Transport 'abnormal load.' The work began with tests on the moment distribution in rectangular beam grillages and was extended to model bridge decks of various kinds. Several reports of this work have been published together with a design procedure incorporating precalculated design charts. Since then tests have been carried out on a box-section bridge composed of precast inverted T-beams, precast diaphragms and precast top slabs which were made as a series of individual units and prestressed together in a number of ways to form a composite box section bridge. The beams were placed side by side to form a continuous hollow box section and the transverse prestress was applied after placing and jointing the precast top slabs. Load tests were carried out in both the elastic and ultimate load ranges with a model of the Ministry of Transport abnormal loading vehicle (see Fig. 11).

Fig. 10.—Typical torsion failure in rectangular beam.

Fig. 11.—Failure of model of box-section bridge deck.

At the working load the behaviour of the bridge was in excellent agreement with that forecast by the load distribution theories which had previously been developed. At ultimate load the failure of the bridge was due to incomplete monolithic action between the precast top slabs and the inverted T-beams. This caused a slightly premature failure of a shear nature with a load factor of 1·9 on the Ministry of Transport abnormal loading. Since it was considered that primary bending failure at ultimate load would be required in practice, a second bridge was constructed using the same precast sections except that on this occasion the inverted T-beams were made on the long-line system. The top slab was cast in situ. The behaviour of the bridge using this method of construction was again in agreement with the load distribution theories and at ultimate load it had a load factor of 2·5 times the Ministry of Transport abnormal loading.

The main conclusions from the tests were that this particular form of bridge is very well suited for the construction of medium and short spans subject to abnormal load. The maximum use of precasting can be obtained and the site work can be reduced to a minimum. A further point of interest was that the load distribution analysis was carried out using a torsional parameter based upon a relaxation technique.

The second complete series of tests was on three composite slabs. These were composed of precast inverted T-beams with in situ concrete between and above them. They were designed for the longitudinal moments from an elastic viewpoint and on an ultimate load basis for the transverse moments.

The first slab tested had no transverse reinforcing steel at all. The strength of the in situ concrete was the same as the strength of the inverted T-beams—10,000 lb. per sq. in. The loading applied to the slab was a model of the Ministry of Transport abnormal loading vehicle and tests were carried out up to ultimate load.

Under the working load conditions, the distribution properties of the slab were about 15 per cent worse that those of an isotropic slab of the same dimensions. At ultimate load, the load factor obtained was 2·7 on the abnormal load and the failure pattern was very similar to that given by a normal yield line analysis (see Fig. 12).

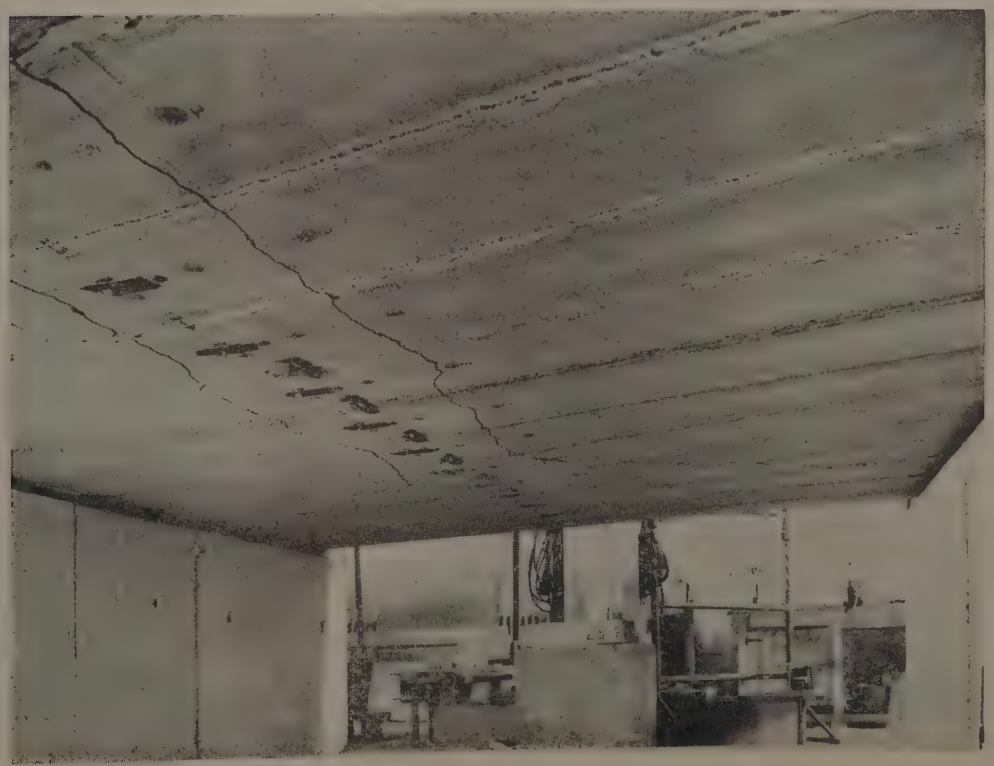


Fig. 12.—Yield-line failure of model composite bridge deck made without transverse reinforcement.

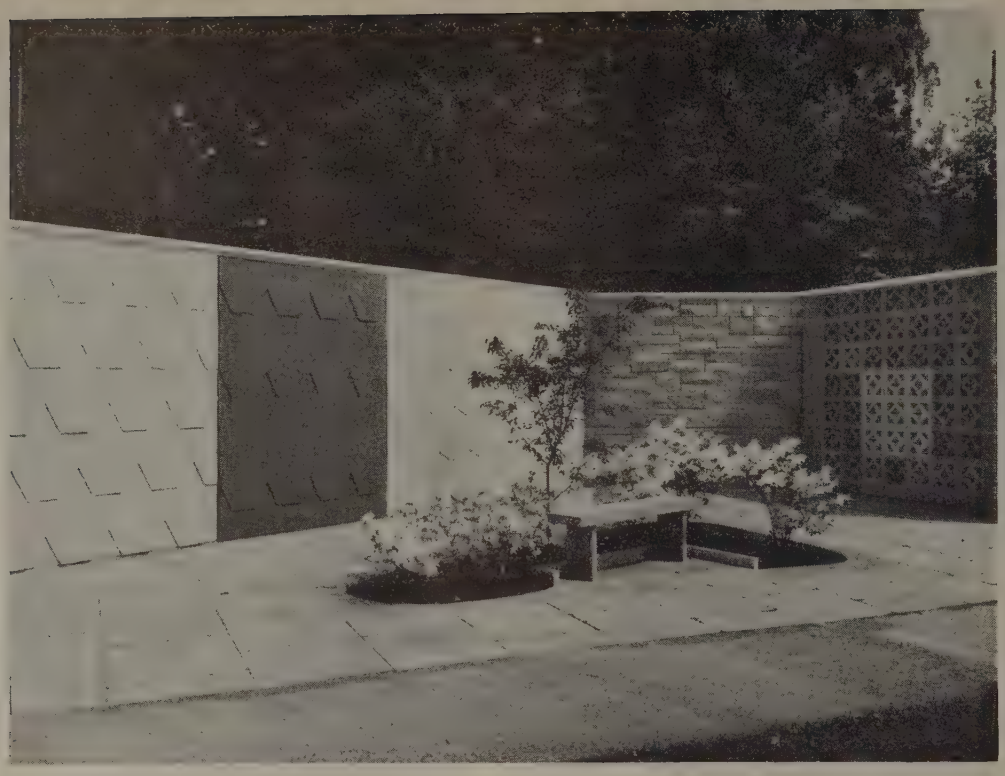


Fig. 13.—A view of part of the exhibition of surface finishes at the Research Station showing concrete block construction.

The second bridge of this type had in situ concrete of 7,500 lb. per sq. in. and mild steel reinforcement designed on a yield line basis. The strength of the precast concrete was 10,000 lb. per sq. in. as in the first bridge. In this case the distribution properties were 10 per cent worse than those of an isotropic slab and the ultimate load factor was 2·9 times the Ministry of Transport abnormal loading.

The third slab had in situ concrete of 4,500 lb. per sq. in. strength with the same mild steel reinforcement as in the second bridge. The behaviour of this was virtually identical with that of the second bridge with the exception that a slightly lower load factor of 2·7 was obtained.

These tests showed that the in situ and precast concrete act effectively together as a composite section and produce the same stiffness as that of a rectangular beam. This contradicts the normally accepted practice of ignoring any in situ concrete below the neutral axis.

It also became clear that in a composite slab there is no need to provide transverse prestressing to ensure adequate behaviour under working load conditions. Mild steel reinforcement is very effective in providing the correct load factor and this steel may be designed on a yield line basis. The stresses recorded in the steel in the last two slabs were not of any magnitude until the ultimate load range was approached.

The two series of tests considered above were for right bridges but it is thought that in practice the results obtained would be valid for degrees of skew of up to about 20.

The problem of skew itself has been considered in other research and a finite difference method of solution for skew slabs has been programmed for a digital computer. Results for 25 bridges of different skew and different span breadth ratios have been obtained in the form of influence co-efficients for deflexions for loads at a number of points within the slab. At the present time a series of tests on skew slabs is being carried out to investigate the yield line method of analysis under a load pattern of the Ministry of Transport abnormal loading type and to check the validity of certain design equations which have been formulated. If these are shown to be correct a suitable design system for skew bridges would be to design on a yield line basis with a check on the working load deflexions utilizing the influence co-efficients mentioned above. Further work is planned on the ultimate load of T-beam bridges with a view to providing similar methods of design for bridges with this type of section.

(*e*) *The Surface of Concrete*

For many years research on concrete has been concentrated on its engineering properties and little attention has been given to its surface appearance.

One of the first projects undertaken by the Association's research station was a study of the problems of appearance. A considerable amount of effort has been devoted to this and to the promotion of the idea that concrete has a good appearance in its own right and has no need of copying other materials. The work has consisted in the main of the development of methods of producing satisfactory surfaces, of demonstrating these surfaces to engineers and architects, and in teaching the technique to those whose function it is to make them. A permanent but constantly changing exhibition of surface finishes has been maintained at the Research Station (see Figs. 13,

Fig. 14.—In situ buff-coloured concrete walling made with carved wooden mould.

14 and 15) and has been inspected by many practising engineers and architects. When necessary, samples of special surfaces have been prepared for particular structures or buildings.

The surfaces that have been developed or displayed fall into three main categories. The first consists of those that owe their effect to exposure of the aggregate, the second consists of tooled surfaces and the third of those that are obtained by casting the concrete in specially prepared or shaped moulds.

The exposed aggregate surface is obtained in various ways. For precast concrete or for the top surface of in situ concrete the aggregate is exposed by brushing and washing before the cement has hardened. For the under-surface of beams or roofs or for precast concrete made face down a similar though not exactly identical effect can be achieved by the sand-bed process in which particles of coarse aggregate are embedded in sand in the bottom of the mould and the concrete cast on top so that the coarse particles become embedded in it. For the vertical faces of in situ concrete the aggregate transfer process is used. In this the aggregate particles are glued to the surface of the mould lining using an adhesive composed of soluble cellulose and fine sand. The aggregate particles become embedded in the concrete and the mould comes away quite readily. All these methods produce a wide range of surfaces according to the size, colour and texture of the aggregate and the colour of the cement used. Exposure tests at Wexham Springs and at Sheffield have shown them to be quite durable and they have been used on more than 1,000 structures during the last few years.

Many of the methods used in tooling concrete present no problem, for they are the same as those used for many years in masonry work. Development work has, however, shown that concrete to be tooled must be batched, mixed and placed with special care in order to avoid variations in composition, segregation and honeycombing. Special attention has also to be given to construction and day-work joints for these will always be visible and should, therefore, be designed accordingly. The idea that tooling can be used as a final resort to improve an unsatisfactory moulded surface has been shown almost invariably to lead to disappointment.

The third method of producing a satisfactory surface is through the use of 'designed' moulds. These may consist of nothing more than carefully arranged shuttering of normal kind with the joints in pre-arranged places, they may consist of timber moulds specially made of boards sometimes of varying thickness arranged in patterns or they may consist of steel plates or have linings of hardboard, aluminium rubber or plastic which may be smooth or patterned.

Moulded surfaces are naturally suited to in situ concrete, but they are often used for precast facing slabs, the so-called 'profiled' slabs or for concrete blocks.

Of the methods of moulding surfaces the one of most immediate interest is that employing a plastic form lining. This lining consists of plain or fibreglass-reinforced plastic sheet moulded into any suitable pattern on a former or by a simple vacuum process. The lining is light in weight, stiff, requires no mould oil, can be used many times, and parts from the concrete very easily, leaving a surface almost as smooth as glass. Surfaces of this kind have been exposed for several years and have so far shown no deterioration.

Many other materials can also be used for form surfaces and successful tests have been made with plywood having an artificially weathered grain or a machined surface. Clay moulds have also been used for certain types of precasting work.

For casting columns the use of large-diameter cardboard tubes was developed in co-operation with the makers and these are now commonly employed in practice.

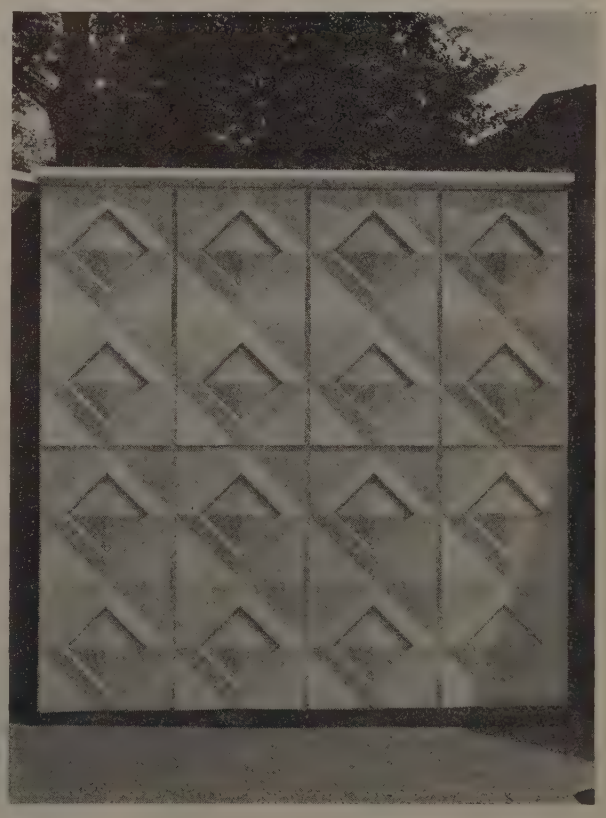


Fig. 15.—Precast concrete facing slabs made with plastic form liners. This concrete has a smooth ceramic-like finish.

Fig. 16.—Gamma-radiography in use. The lead container on the left contains a source of Cobalt 60 and the photographic plate is in the envelope against the beam.

The method has been of use not only in locating bad workmanship and determining the cause of faults but also in establishing the strength of old structures of which the drawings have been lost.

Techniques developed in the course of normal research on structures are also proving of value to the practising engineer. Mention has already been made of the use of an electronic digital computer for the calculation of the influence of co-efficients for skew bridges. The computer is becoming of considerable value to the research worker for general data processing, and there is a trend for the results of research, especially those concerned with design procedures, to be presented in the form of either computer programmes or of tables of co-efficients prepared by computation, as for skew bridges. Several programme specifications have already been prepared and issued by the Association.

Close co-operation of a similar kind is also being developed in the field of structural model testing. Models have for long been a normal stage in design procedure. Michaelangelo once said " A builder's most blessed expense is the money spent on models," and models were used by the great Victorian engineers. The present day use of models is, however, somewhat different, for their main purpose is normally to resolve some specific difficulty or ambiguity in a design, and the tests often involve many measurements of strain or deflexion and loading to destruction. The

(f) Field Testing Techniques and Advisory Work

As has already been mentioned, a research organization often develops testing techniques of value to those in practice. They may help in design, may trace the cause of failures, may overcome construction difficulties, and may be of use when doubt arises regarding the quality of work done in practice.

Much of the work of the Chemistry and Physics Department is involved in the application of its specialized knowledge and measuring equipment to engineering problems, and it has, of course, in its analytical laboratory and X-ray diffractometer special means of identifying the causes of chemical deterioration of concrete or in determining mix proportions. Various items of special apparatus have also been specially designed for helping in the construction field. The first was the now well-known ' covermeter ' for locating reinforcement and measuring its depth below the surface of concrete. Another technique giving similar but more complete information is that of gamma radiography. This produces an ' X-ray picture ' of the concrete, but the apparatus is much cheaper and simpler than that required for X-radiography. It consists essentially of a radio-active cobalt source in a safety container. This is placed on one side of the specimen under test and a photographic plate in an envelope is placed on the other (see Fig. 16). Exposure is made by opening a ' window ' in the safety container. Time depends on the strength of the source and on the thickness of the concrete, but is commonly of the order of half or one hour for concrete 12 to 18 in. thick. The radiograph shows the size and position of all steel and whether it is corroded, indicates honeycombing and sometimes cracks and shows cavities such as inadequately grouted prestressing ducts (see Fig. 17). By making double stereoscopic exposures the spacing of reinforcement in the line of radiation can be determined.

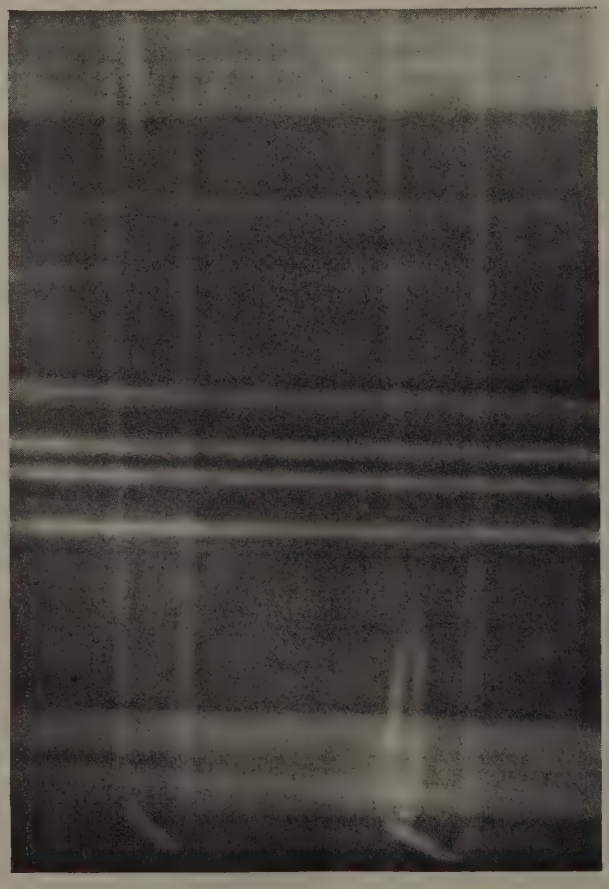


Fig. 17. Gamma-radiograpl. of a prestressed beam. The horizontal dark line in the centre of the picture immediately above the top prestressing wire indicates inadequate grouting.

Fig. 18.—Laboratory test on model of the Fleet bridge.

Fig. 19.—The Ministry of Transport ' abnormal load ' vehicle.

experience obtained by the Association in testing models and their related full-scale equivalents in the research on bridges (see Figs. 18 to 21), and the model-making skill developed by the staff, has led to an increasing confidence in the use of model technique in forecasting structural behaviour. Several models of proposed structures have been tested in recent years at the request of designers (see Figs. 22 to 25), and the Association is now providing a service in this field.

Apart from its value in determining various factors in connection with a structural design a model test is sometimes useful in improving construction technique and always results in a fruitful collaboration between research worker and designer. The distinction between design office and research laboratory becomes in these conditions very blurred.

Fig. 20.—Full-scale test of the Fleet bridge, Hampshire, using the Ministry of Transport ' abnormal load ' vehicle.

Fig. 21.—Full-scale test at maker's works on a main beam of the Chiswick fly-over.

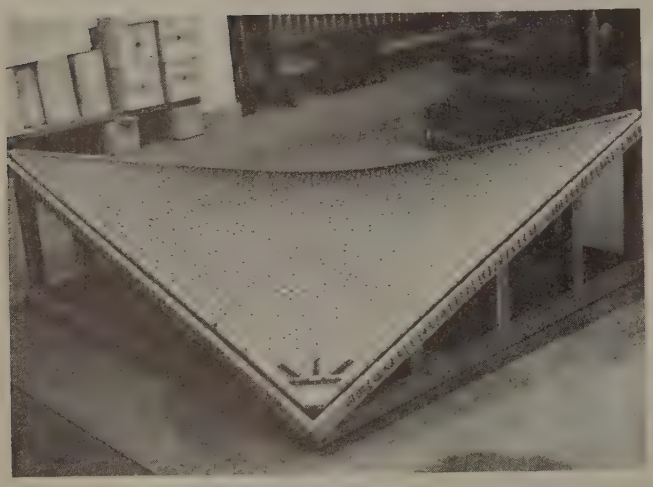


Fig. 22.—Model of a hyperbolic-paraboloid roof under construction.

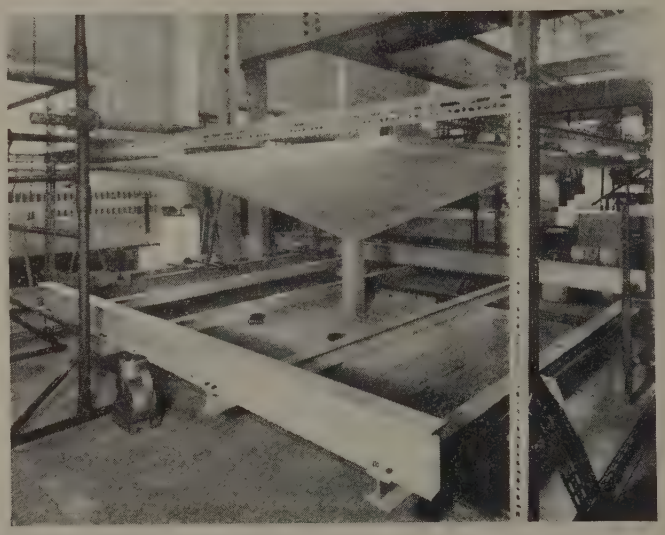


Fig. 24.—Model of a four-unit hyperbolic-paraboloid roof.

Fig. 23.—Model of a tied hyperbolic-paraboloid roof under test.

Fig. 25.—Model of one main box-section cantilever of a 500 ft. span prestressed bridge.

4. The Dissemination of Results

The theme of co-operation between research and industry has run all through this paper, but co-operation is nearly always of a personal nature and it is still necessary to disseminate the results of research on a wider scale.

Applied research is only half done when the results have been obtained, and it is essential that the information should be passed on to those who need or can use it. Even this may not be enough, for the potential user may not appreciate his own need and some effort may be required to demonstrate the value of the information, especially if the research has shown that some greater than normal initial expense should be incurred in order to avoid future troubles.

For this function the Association adopts a policy of combining publications with education and field advisory services. The results of research are first presented in typewritten 'Technical Reports' which are prepared as quickly as possible and sent to other research organizations, special libraries and anyone known to be specially interested in the subject. These reports are often of an interim nature and their early limited circulation has the advantage of informing other research workers and specially interested users of what is being done, so preventing overlapping and encouraging co-operation. At a later stage the reports, sometimes singly, sometimes in combination, and sometimes abbreviated, appear as papers to learned societies, articles in the technical press, in the Association's own Magazine of Concrete Research, or as printed 'Research Reports' published by the Association. When necessary or appropriate an individual report may be given a wide special circulation among a particular group or groups of users.

The dissemination of results through education takes place concurrently with the research itself through the advisory services of the Association, through some 800 lectures a year to societies, universities, technical colleges and other bodies, and at training courses at the Research Station, and through talks to most of the 3,000 visitors who come every year to the Research Station.

The training courses occupy an important place in this process. They take place in a specially constructed building containing a lecture hall, recreational facilities and thirty-six bedrooms. The courses are residential and normally occupy one week each. They consist of lectures by both research and teaching staff and include practical demonstrations, visits to sites and sometimes lectures by experts from outside the Association. Each course is specialized in subject and in audience. For example, there are separate courses on structural concrete, on mix design, on bridge design or on road construction, and audiences are either engineers, foremen, architects, lecturers at universities or technical colleges or from some specialized industrial group.

The chief value of the courses lies in two-way traffic of ideas that occurs. The research worker has to formulate and explain his results in practical terms and receives comments, criticisms and questions that help him guide his research along the most useful lines. On the other hand, the person attending the course absorbs some of the atmosphere of the research laboratory, receives his information direct and has to submit his own comments and queries to the questioning examination of the research worker.

It is fully realized that the publications, the visits, the lectures and training courses do not in themselves perform the function of ensuring the application of research. They make it easier for the practitioner to obtain information but he must still search and wish to search to some extent for the results of research. In doing this he may find what he needs though not always what he wants to know, for the research worker tries only to understand the laws of Nature ; however much he succeeds he cannot change them.

5. Acknowledgment and Bibliography

In published papers it is not unusual to find acknowledgment of help given to the Author and a bibliography. This paper is in this respect a special case, and it is felt that the normal forms are inappropriate.

A research station is not a collection of laboratories ; it is primarily a team in which everyone plays an essential part, including those who provide the funds and give advice.

This paper is an account of the work of one of those teams not only as it stands at the moment but also including those who have at various times served and left it. It would be impossible to give all their names and inadequate to give less than all.

For a similar reason no attempt will be made to give a bibliography. A complete list of reports can, in any event, be obtained from the Association.

Book Review

Descriptive Geometry, 2nd Edition, by E. G. Paré, R. O. Loving, and I. L. Hill. (New York and London : The Macmillan Co., 1959) 9½ in. × 6 in., 349 plus viii pp. 35s.

This is the second edition of a practical book in which the text is divided into short chapters, each of which concludes with abstract and laboratory problems based on the subject matter of the chapter, with emphasis on fundamentals and new engineering experiences. Solutions of the problems included have been broken into the necessary steps to make the construction easy to follow, and whenever possible solutions in pictorial form have been included. The last chapter reviews the material already dealt with and contains the solution of a number of problems involving several principles.

The text in the new edition has been revised and expanded, some of the problems included in the first edition have been revised or replaced, and many new examples have been added.

Institution Notices and Proceedings

ORDINARY GENERAL MEETING

An Ordinary General Meeting of the Institution of Structural Engineers was held at 11, Upper Belgrave Street, London, S.W.1., on Thursday, 28th January, 1960, at 5 p.m. Mr. Lewis E. Kent, B.Sc., M.I.Struct.E., M.I.C.E. (President), in the Chair.

The following members were elected in accordance with the Bye-Laws. Will members kindly note that the elections, as tabulated below, should be referred to when consulting the Year Book for evidence of membership.

Students

Breebaart, Johannes, of Pretoria, South Africa.
Clements, Patrick, of Bristol.
Exton, John, of Crich, nr. Matlock, Derbyshire.
Grafton, James Patrick, of Brighton, Sussex.
Gupta, Siba Prosad, B.Sc., of Calcutta, India.
Hull, Brian, of Manchester.
Krailing, Derek, of Twickenham, Middlesex.
Morton, Darryl Arthur, of Boksburg, South Africa.
Ng Sai-Wah, of Stafford.
Ogundehin, Oladipupo Remi, of Lagos, Nigeria.
Patel, Shankarbhai Sendhabhai, of Langhnaj, North Gujarat, India.
Pritchard, Carl, of Lincoln, Lincolnshire.

Graduates

Ballentyne, Michael John, of Sydney, New South Wales, Australia.
Bishop, Roger, of Romford, Essex.
Chaudhuri, Ajoy Kumar, B.Sc., of Glasgow.
Eid, Hag Bashir Mohemed, of Khartoum, Sudan.
Hussain, Ajmal Ibrahim, B.Eng., of London.
Hynd, Donald Cameron, of Motherwell, Lanarkshire.
Jones, Jack William, of Enfield, Middlesex.
Kao Wu, Timothy, B.Sc., of Hong Kong.
Osobamiro, Samuel Adewole, B.Sc., of Darlington, Co. Durham.
Pountney, Alan, of Tipton, Staffs.
Price, Robert Norman, B.Sc.Tech., of Bootle, Lancashire.
Quigley, Peter, of Manchester.
Wayment, Robert, of London.
Wilde, Brian Richard, B.Eng., of Golborne, nr. Warrington, Lancashire.

Member

Byers, Charles Thomas Albert, of Beckenham, Kent.

Transfers

Students to Graduates

Bradshaw, Rodney Edward, of Hornchurch, Essex.
Deakin, William Herbert, of Swinton, nr. Manchester.
Gibson, Alexander James, of Glasgow.
Nicholson, Trevor, of Scunthorpe, Lincolnshire.

Graduates to Associate-Members

Bagshaw, Grenville, of New Broughton, nr. Wrexham, Denbighshire.
Hawkes, Cyril Dickson, of London.
Kelsey, Peter John, of London.
Sen Gupta, Prabhas, B.Eng., of Calcutta, India.
Tompkins, David Edward Alfred, of London.

Associate-Members to Members

Gooding, Philip Henry Thomas, of London.
Heath, Peter Geoffrey, of Solihull, Warwickshire.
Parish, Jack Leonard James, of Darlington, Co. Durham.
Ranger, Bernard Esmond Selby, A.M.I.C.E., of Leatherhead, Surrey.
Shrimpton, Arthur Philip, B.Sc., M.I.C.E., of Blaenau Ffestiniog, Merionethshire, North Wales.

Associate-Members to Retired Associate-Members

Brown, George Frederick, of Teddington, Middlesex.
Goodfellow, Reginald Francis, of Richmond, Surrey.

Members to Retired Members

Heathcote, John, of Manchester.
Ramsay, James Simpson Scotland, M.I.C.E., of Surbiton, Surrey.
Sevian, Vahe Joseph, of Baghdad, Iraq.
Westacott, John, of Sutton Valence, nr. Maidstone, Kent.

OBITUARY

The Council regret to announce the deaths of Peter Holgate (Member); Captain Horace John Barwick (Retired Member); Ernest Purton (Retired Associate-Member).

RESIGNATIONS

Notification was given that the Council had accepted with regret the resignations of Bertie Robinson (Associate-Member); Syed Mobin Ahmad, Vaman Dattatraya Borkar, Thomas Lange, Derek Edward Peatfield, Mariappa Subramanya, Thomas Edwin Bedford (Graduates).

CORRECTION

Graduates Elected 17th December, 1959

It is regretted that the heading "Graduates" was omitted from the list of elections to membership published in the February issue of the Journal, where the names of the newly-elected Graduates appeared under the same heading as the Students. At the Ordinary General Meeting of the Institution of Structural Engineers held on the 17th December, 1959 the following Graduates were elected :—

Graduates

Basu, Amiya Kumar, B.E., of Croydon, Surrey.
Boxall, William Derek, B.Eng., of Wirral, Cheshire.
Burchess, David Sydney, of Bromley, Kent.
Bryan, Hugh, of Westerham, Kent.
Castleman, Maurice, of Sanderstead, Surrey.
Caton, John, B.Sc., of Blackburn, Lancashire.
Chatarjea, Sukhendu, B.E., of Calcutta, India.
Chopra, Ramesh Chandra, B.Eng., of Calcutta, India.
Collins, Terence Roy, of London.
Das, Suniti Bhusan, B.Eng., of London.
De Souza, Clarence Anthony, of Stockton-on-Tees, Co. Durham.
Fletcher, Bernard George, of Upper Belvedere, Kent.
Ganapathy, Ramalingam, B.Sc., of Bombay, India.

GHOSHAL, Amitabha, B.Eng., of Calcutta, India.
GREIG, Peter John, of Barking, Essex.
HARRIS, Ian Roy, of Brentwood, Essex.
HILL, Kenneth Brian, of Heston, Middlesex.
HOLT, Eric John, of Enfield, Middlesex.
HORVATH, Alfred, of London.
KARNIK, Arun Balkrishna, B.E., B.Sc., of Bombay, India.
LACEY, Brian George, of London.
LEE TONG YEW, of Johore, Malaya.
LOCKHART, Ronald Henry, of Glasgow.
MANOHAR, Sharad Narayan, M.Sc., B.E., of London.
NICHOLLS, Michael George, of London.
ODELL, Jack Stewart, of London.
PERRY, Ronald, B.E., of London.
SIBLEY, Ronald James, of Southampton.
SOYANNWO, Olusola Sofoluwe, of London.
STABHOLZ, Albert, B.Sc., of London.
STEEDMAN, James Cyril, of Brighton, Sussex.
SWINDALE, Cyril Ernest, of London.
TATE, Geoffrey Michael, of Sheffield.
TAYLOR-LEWIS, Sylvanus Eliasaph Abosede, B.Sc., of Birmingham.
TURNER, James Albert, B.A., of Leicester.
WALKER, Geoffrey Charles, of Tamworth, Staffordshire.
WHITE, Geoffrey Frederick John, of London.
YATES, Peter, of York.
ZEKARIA, Isaac Ezra, M.Sc., of London.

FORTHCOMING MEETINGS

The following meetings of the Institution will be held at 11, Upper Belgrave Street, London, S.W.1.

Thursday, 10th March, 1960

Ordinary Meeting at 6 p.m., when three papers on "New Developments in Structural Analysis and Design by means of the Electronic Computer" will be given as follows :—

Mr. L. Morgan : "Application of an Electronic Digital Computer to Structural Steel Design."

Dr. E. Lightfoot, M.I.Struct.E., A.M.I.C.E., and Mr. F. Sawko : "The Analysis of Grid Frameworks and Floor Systems by the Electronic Computer."

Dr. D. M. Brotton, A.M.I.Struct.E. : "Elastic Critical Loads of Multi-Bay Pitched Roof Portal Frames with Rigid External Stanchions."

ADDITIONAL MEETING

Wednesday, 16th March, 1960

An additional meeting has been arranged and will be held jointly with the Reinforced Concrete Association at 11, Upper Belgrave Street, London, S.W.1., on Wednesday, 16th March, 1960, at 6 p.m., when Professor A. L. L. Baker, D.Sc.(Eng.), M.I.Struct.E., M.I.C.E., will present "A Further Report on the Work of the European Committee on Concrete." The paper follows on from that given at a Joint Meeting of the Institution and the Association on the 23rd January, 1958. Copies of the paper to be given on the 16th March may be obtained on application to the Secretary, The Reinforced Concrete Association, York Mansion, 94-98, Petty France, London, S.W.1.

Thursday, 24th March, 1960

Ordinary General Meeting for the election of members 5.55 p.m., followed by an Ordinary Meeting at 6 p.m., when a paper on "Research for the Concrete Industry" will be given by Dr. A. R. Collins, M.B.E., M.I.Struct.E., M.I.C.E. (Member of Council).

Thursday, 28th April, 1960

An Ordinary General Meeting for the election of members will be held on Thursday, 28th April, 1960, at 5 p.m.

Thursday, 26th May, 1960

Ordinary General Meeting for the election of members at 5.55 p.m., followed by the Annual General Meeting at 6 p.m.

Members wishing to bring guests to the Ordinary Meetings announced above are requested to apply to the Secretary for tickets of admission.

EXAMINATIONS, JULY, 1960

The Examinations of the Institution will next be held in the United Kingdom and overseas on Tuesday and Wednesday, July 12th and 13th, 1960 (Graduateship) and Thursday and Friday, July 14th and 15th, 1960 (Associate-Membership).

INSTITUTION EXAMINATIONS, JULY, 1961

The revised examinations of the Institution will take place in July, 1961. Details of the syllabuses and of the exemptions from the Graduateship Examination and partial exemptions from the Associate-Membership Examination which will become operative at the same time, may be obtained on application to the Secretary of the Institution.

COMMON PRELIMINARY EXAMINATION

The Engineering Joint Examination Board, which for many years has conducted the Common Preliminary Engineering Examination, will be disbanded at the end of this year. Qualifications for Studentship of the Institution, which will become operative in January, 1961, may be obtained on application to the Secretary of the Institution.

REPRESENTATION

The Council have appointed the following Institution representatives :

British Standards Institution Sub-Committee CEB/6/4—Concrete Kerbs and Flags—
Mr. W. Hunter Rose (Member).

Code of Practice for Precast Factory Made Concrete
Mr. A. F. Holt (Member)
Mr. O. J. Masterman (Member)
Mr. D. H. New (Member)
Mr. W. Hunter Rose (Member)
Mr. Hunter Rose has been appointed Chairman of the Committee.

OVERSEAS REPRESENTATIVE

The Council have appointed Mr. W. N. Dunn (Associate-Member) Institution representative in West Pakistan.

INSTITUTION REPORTS

Report 31/1950, on the Structural Use of Aluminium Alloys in Buildings, has been withdrawn.

The Council have decided that Report 32/1951, the First Report on Prestressed Concrete, shall not be reprinted since it is now superseded by CP 115.

INSTITUTION LIBRARY

Facilities for lending books from the Library have now been extended to members in Eire.

READERSHIP IN STRUCTURAL ENGINEERING AT SOUTHAMPTON UNIVERSITY

As announced in the *Journal* in January, 1959, the Faculty of Engineering in the University of Southampton introduced in October, a course leading to the degree of B.Sc.(Engineering) in Structural Engineering. Through the generosity of a number of donors, the Council of the Institution of Structural Engineers has been able to provide for a Readership in Structural Engineering at the University by making available a sum of £2,000 per annum, for a period of seven years under covenant. The University Council has accepted the Institution's offer and at the end of the seven years' period will provide the necessary funds for the continuance of the Readership.

The Council of the Institution is greatly indebted to the following contributors whose generosity has made it possible for the Readership to be established :—

Dawnays Ltd.
J. Starkie Gardner Ltd.
Griggs & Sons Ltd.
Holland & Hannen and Cubitts Ltd.
Holloway Brothers (London) Ltd.
Holst & Co., Ltd.
John Laing & Son Ltd.
Marshall Andrew & Co., Ltd.
Matthews & Mumby Ltd.
F. C. Minter Ltd.
Monk & Co., Ltd.
John Morris (Publicity) Ltd.
Mowlem & Co., Ltd.
Wilfred Pring, Esq.
Bernard Sunley & Son Ltd.
Taylor Woodrow Ltd.
Trollope & Colls Ltd.
Wates Ltd.

HONOURS AND AWARDS

In offering their sincere congratulations to the following members on the distinctions recently conferred upon them, the Council feel they are also expressing the good wishes of the Institution.

Knight Bachelor
Dr. W. H. Glanville (Member).

Order of St. Michael and St. George—C.M.G.
Mr. T. A. L. Paton (Member).

Order of the British Empire—K.B.E.
Brigadier D. L. Anderson (Member)

Order of the British Empire—O.B.E.
Mr. D. J. Dunn (Member)

ASSOCIATION OF CONSULTING ENGINEERS

The Association of Consulting Engineers have amended their Articles of Association whereby full Membership of the Institution of Structural Engineers will be accepted as a qualification for Membership of the Association of Consulting Engineers.

THE MAITLAND LECTURE COMPETITION

A competition will be held for the Maitland Lecture which will be given during the Session 1960-61. Members and Associate-Members of the Institution are invited to submit a written lecture, the subject of which may be on research, design or construction in the field of structural engineering, with special reference to new developments.

The winner of the Competition will be awarded the Maitland Silver Medal and Premium (value £100).

Lectures submitted for the Competition must be received by the Institution not later than the 31st March, 1960. Further information regarding the conditions of the Award may be obtained on application to the Secretary.

SYMPOSIUM ON NUCLEAR REACTOR CONTAINMENT BUILDINGS AND PRESSURE VESSELS

A Symposium on Nuclear Reactor Containment Buildings and Pressure Vessels is to be held at the Royal College of Science and Technology, Glasgow, from the 17th to 20th May, 1960.

The advent of large containment buildings and pressure vessels in the field of nuclear power engineering introduced problems of analysis, design, construction, inspection and testing of an unconventional character and relative complexity. Research and development work relevant to these problems is being carried on in a number of industrial and academic centres and it is felt that all who work in this field will welcome the opportunity of exchanging information.

The Symposium will comprise five technical sessions at which a total of twenty one papers, contributed from this country and America, will be presented. The following is a summary of the programme :—

Tuesday, 17th May, 1960

Morning Session.—Current practice and future trends in the United Kingdom regarding principal reactor types and the corresponding forms of pressure vessels and containment buildings. Pressure vessels appropriate to gas-cooled reactor projects and the functional specification of reactor containment. Safety requirements in design, construction, inspection and operation of nuclear reactors in relation to containment. The use of reinforced concrete in containment buildings.

Afternoon Session.—Containment design practice and future developments in the United States and the United Kingdom. The major items affecting the engineering design of containment buildings and pressure vessels. Methods of stress analysis of spherical vessels and its associated structures.

Wednesday, 18th May, 1960

The results of analytical and experimental research investigations carried out in the United States and the United Kingdom on problems such as the effects of loads transferred by nozzles, discontinuity stresses at cut outs and at shell and skirt connections, thermal stresses and the effects of creep.

Thursday, 19th May, 1960

As a preliminary to the last session of the Symposium dealing with the construction, testing and inspection of containment buildings and pressure vessels this day is set aside for visits to a heavy pressure vessels fabricating firm and to a nuclear power station. These visits form an integral part of the Symposium proceedings and no technical sessions will be held on this day.

Friday, 20th May, 1960

Morning Session.—The limitations imposed on design of the practical difficulties on site, plate forming and welding techniques, prefabrication and erection of heavy pressure vessels ; testing and inspection. Illustrative film records.

Afternoon Session.—' Open Topic ' discussion and outline summary of main points brought out during the Symposium.

The Symposium is organised by the Department of Mechanical, Civil and Chemical Engineering of The Royal College of Science and Technology, Glasgow. Registration forms to take part in the Symposium, which should be completed and returned not later than 1st April, 1960, may be obtained from the Secretary of the College, George Street, Glasgow, C.1.

JOURNAL CASES AND BINDING, 1959

A binding case can be supplied for the twelve issues of the Journal, January-December, 1959 (Volume 37), price 12s. 6d. including postage. The price for binding in half-leather, inclusive of packing and postage, is 31s. 0d. per volume.

It is requested that all parcels containing Journals forwarded for binding should bear the name and address of the sender and must be despatched to reach the Institution by the 30th April, 1960.

An index will be included in all bound volumes.

Members making their own arrangements for binding may obtain a copy of the Index upon application to the Secretary.

SESSIONAL PROGRAMME

The Literature Committee have under consideration the selection of papers for inclusion in the Sessional Programme for 1960-61. Members who may wish to offer papers during the coming Session are invited to communicate with the Secretary.

Branch Notices

LANCASHIRE AND CHESHIRE BRANCH

The following meetings have been arranged :—

Wednesday, 2nd March, 1960

Joint Meeting with the Institute of Welding, 7.15 p.m.

Mr. A. V. Hooker, M.I.Struct.E., M.I.C.E., on " Welding in the Structural Industry."

Thursday, 10th March, 1960

Junior Members' Evening for the presentation of three 20-minute papers by the following Branch members :—

Mr. G. Evans, A.M.I.Struct.E. : " The Design and Construction of the Plutonium Criticality Facility Building at Dounreay."

Mr. T.L. Holden (Graduate) : " The Construction of a Laminated Timber Hyperbolic Paraboloid Roof."

Mr. C. Tucker, A.M.I.Struct.E. : " British Railways —London Midland Region Electrification. Reconstruction of overbridges between Crewe and Manchester."

In the New Lecture Theatre, U.K.A.E.A. (I.G.) Headquarters, Risley, nr. Warrington.

Friday, 18th March, 1960

Dr. D. D. Matthews, M.I.Struct.E., M.I.C.E. (Vice-President), will present a paper from notes provided by M. Esquillan on " The Design and Construction of the Exhibition Palace of the National Centre of Industries and Technology, Paris." It is hoped M. Esquillan will be present.

Thursday, 7th April, 1960

Annual General Meeting.

Unless otherwise stated the above meetings will be held at the College of Science and Technology, Manchester, commencing at 6.30 p.m. Light refreshments will be available from 5.45 p.m.

MERSEYSIDE PANEL

The following meetings have been arranged :—

Wednesday, 6th April, 1960

Joint Meeting with the Liverpool Architectural Society.

Mr. Howard V. Lobb, C.B.E., F.R.I.B.A., on " Nuclear Power Stations."

At Bluecoat Chambers, School Lane, Liverpool, commencing at 6 p.m.

Monday, 18th April, 1960

Annual General Meeting of the Merseyside Panel.

At the Liverpool Engineering Society, The Temple, Dale Street, Liverpool, at 6.30 p.m., preceded by light refreshments from 5.30 p.m.

Friday, 6th May, 1960

Annual Dinner Dance.

At the Carlton Club, Eberle Street, Liverpool.

Hon. Secretary : W. S. Watts, A.M.I.Struct.E., A.M.I.C.E., 11, Newchurch Lane, Culcheth, nr. Warrington, Lancs.

MIDLAND COUNTIES BRANCH

The following meetings have been arranged :—

Tuesday, 8th March, 1960

Mr. A. W. Hill, B.Sc.(Eng.), M.I.Struct.E., M.I.C.E., M.I.Mun.E., on " The Structural Use of Prestressed Concrete in Buildings C.P.115,"

At the Electricity Showrooms, Irongate, Derby, at 6.15 p.m. Tea will be served from 5.30 p.m.

Friday, 25th March, 1960

Mr. A. W. Hill, B.Sc.(Eng.), M.I.Struct.E., M.I.C.E., M.I.Mun.E., on " The Structural Use of Prestressed Concrete in Buildings C.P.115."

Friday, 22nd April, 1960

Annual General Meeting, followed by a lecture details of which will be announced.

Unless otherwise stated, meetings will be held at the James Watt Memorial Institute, Great Charles Street, Birmingham, at 6.30 p.m. Tea will be served from 5.45 p.m.

Hon. Secretary : S. M. Cooper, A.M.I.Struct.E., " Applegarth," Hyperion Road, Stourton, nr. Stourbridge, Worcestershire.

GRADUATES' AND STUDENTS' SECTION

The following meetings have been arranged :

Friday, 4th March, 1960

Mr. N. Rayman, Chief Structural Engineer to the City of Coventry, on " The New Coventry."

Friday, 1st April, 1960

Mr. A. T. Clarke, M.I.Struct.E., Branch Chairman, on " Some Experiences and Faults in Reinforced and Prestressed Concrete."

Followed by the 13th Annual General Meeting.

Friday, 6th May, 1960

Third Annual Buffet Dance, at the Station Hotel, Dudley.

The above meetings will be held at the Birmingham Exchange and Engineering Centre, Stephenson Place, Birmingham, commencing 6.30 p.m. Tea will be served from 6 p.m.

Hon. Secretary : H. T. Dodd, Shepherd's Cottage, Grove Lane, Wishaw, Sutton Coldfield, Warwickshire.

NORTHERN COUNTIES BRANCH

The following meetings have been arranged :

Tuesday, 1st March, 1960

At Middlesbrough. Mr. Walter C. Andrews, O.B.E., M.I.Struct.E., M.I.C.E. (Past President) on " The Provisions of the Revised British Standard for the Use of Structural Steel in Building—B.S.449/1959."

Wednesday, 2nd March, 1960

The above paper will be repeated at Newcastle.

Friday, 18th March, 1960

At Newcastle. Mr. J. H. H. Gillespie, B.Sc., A.M.I.Struct.E., A.M.I.C.E., on " The Modernisation of British Waterways with particular reference to the South Eastern Division."

Tuesday, 5th April, 1960

At Middlesbrough. Mr. Frederick S. Snow, C.B.E., M.I.Struct.E., M.I.C.E., M.I.Mech.E. (Past President), and Mr. E. V. Finn, A.M.I.Struct.E., A.M.I.C.E., on " The Structural Engineering Aspects of the Development of Gatwick Airport."

Wednesday, 6th April, 1960

At Newcastle. Annual General Meeting, after which the above paper will be repeated.

Friday, 22nd April, 1960

Annual Dinner.

At the Corporation Hotel, Middlesbrough.

Unless otherwise stated, meetings in Middlesbrough will be held in the Cleveland Scientific and Technical Institution and meetings in Newcastle will be held in the Neville Hall, commencing at 6.30 p.m., preceded by buffet tea at 6 p.m.

Hon. Secretary : P. D. Newton, B.Sc., A.M.I.Struct.E., A.M.I.C.E., c/o Richard Hill Ltd., P.O. Box 29, Middlesbrough, Yorkshire.

NORTHERN IRELAND BRANCH

The following meetings have been arranged :

Tuesday, 1st March, 1960

Annual Function.

Tuesday, 5th April, 1960

Annual General Meeting and Film Evening.

Meetings will be held in the Civil Engineering Department of the Queen's University of Belfast at 6.30 p.m., unless otherwise notified, and will be preceded by tea at 5.45 p.m.

Hon. Secretary : L. Clements, A.M.I.Struct.E., A.M.I.C.E., A.M.I.Mun.E., 3, Kingswood Park, Cherryvalley, Belfast.

SCOTTISH BRANCH

The following meetings have been arranged :

Tuesday, 15th March, 1960

Mr. W. G. N. Geddes, B.Sc., M.I.Struct.E., M.I.C.E., on " Piling in Structural Engineering."

Tuesday, 19th April, 1960

Annual General Meeting.

The above meetings will be held at The Institution of Engineers and Shipbuilders, 39, Elmbank Crescent, Glasgow, commencing 7 p.m.

Hon. Secretary : W. Shearer Smith, M.I.Struct.E., A.M.I.C.E., c/o The Royal College of Science and Technology, George Street, Glasgow, C.1.

SOUTH WESTERN SECTION

The following meeting has been arranged :

Friday, 11th March, 1960

In Plymouth. Mr. J. D. Norfolk, M.I.Struct.E., A.M.I.C.E., A.M.I.Mun.E., on " The New Queen Elizabeth Dock at Falmouth."

At the Duke of Cornwall Hotel, 6 p.m. Tea 5.30 p.m.

Hon. Secretary : C. J. Woodrow, J.P., " Elstow," Hartley Park Villas, Mannamead, Plymouth, Devon.

WALES AND MONMOUTHSHIRE BRANCH

The following meetings have been arranged :

Wednesday, 9th March, 1960

At Swansea. Junior Members' Evening. Papers will be given by Graduates and Students.

Friday, 8th April, 1960

Annual Dinner.

At Swansea.

Wednesday, 4th May, 1960

Annual General Meeting.

At Swansea.

Meetings will be held at the Mackworth Hotel, High Street, commencing 6.30 p.m.

Hon. Secretary: K. J. Stewart, M.I.Struct.E., A.M.I.C.E., 15, Glanmor Road, Swansea.

WESTERN COUNTIES BRANCH

The following meetings have been arranged :

Friday, 4th March, 1960

Combined Meeting with the Institution of Civil Engineers.

Mr. H. G. Cousins, B.Sc., M.I.Struct.E., M.I.C.E., on " Concrete Structures."

Friday, 1st April, 1960

Annual General Meeting 6 p.m., followed at 7 p.m., by a paper to be given by Mr. John Mason, B.A. (Cantab.), M.I.Struct.E., A.M.I.C.E. (Hon. Treasurer) entitled " A Commentary on the new British Standard 449 (1959). The Use of Structural Steel in Building."

Meetings will be held in the Small Lecture Theatre, University Engineering Laboratories, University Walk, Bristol 8, commencing 6 p.m., preceded by tea at 5.30 p.m.

Hon. Secretary : A. C. Hughes, M.Eng., A.M.I.Struct.E., A.M.I.C.E., 21, Great Brockeridge, Bristol 9.

YORKSHIRE BRANCH

The following meetings have been arranged :

Wednesday, 2nd March, 1960

At Scunthorpe. Joint Meeting with the East Midlands Association of the Institution of Civil Engineers.

Dr. K. C. Rockey, A.M.I.C.E., A.M.I.Mech.E., on " Web Buckling and the Design of Web Plates."

At the Blue Bell Hotel, 6.30 p.m.

Wednesday, 16th March, 1960

At Leeds. Joint Meeting with the Yorkshire Association of The Institution of Civil Engineers and the Yorkshire and Lincolnshire Branch of the Institution of Highway Engineers.

Mr. J. M. Fisher, B.Sc., M.I.C.E., Dr. A. R. Lee, A.I.C.E., and Dr. R. S. Millard, M.I.C.E., on "Research and its Application to Road Construction."

Wednesday, 23rd March, 1960

At Hull. Joint Meeting with the Hull and East Riding Branch of the Institution of Civil Engineers. Mr. F. R. Bullen, B.Sc.(Eng.), M.I.Struct.E., M.I.C.E., (Vice-President) on " The Bearing Capacity of Driven Piles."

In the Lecture Theatre, Electricity Building, Ferensway, 6.15 p.m.

Friday, 1st April, 1960

At York. Annual Dinner and Dance.

At the Royal Station Hotel, 7 p.m.

Wednesday, 6th April, 1960

At Sheffield. Mr. H. J. Purkis, B.A., B.Sc., on "The Present Position of Sound Insulation in Buildings."

Wednesday, 20th April, 1960

At Leeds. Annual General Meeting, followed by a paper given by Mr. E. J. Martin, M.I.Struct.E., entitled " Reinforced Concrete Construction for a new Limestone Quarrying and Treatment Plant."

Meetings in Leeds will be held at the Metropole Hotel, King Street, and in Sheffield at the Royal Victoria Hotel. Meetings will commence at 6.30 p.m., preceded by buffet tea at 6.15 p.m.

Hon. Secretary : W. B. Stock, A.M.I.Struct.E., 34, Hobart Road, Dewsbury, Yorks.

UNION OF SOUTH AFRICA BRANCH

Hon. Secretary : A. E. Tait, B.Sc., A.M.I.Struct.E., A.M.I.C.E., P.O. Box 3306, Johannesburg, South Africa.

During weekdays Mr. Tait can be contacted in the City Engineer's Department, Town Hall, Johannesburg. Phone 34-1111, Ext. 257.

Natal Section Hon. Secretary : J. C. Panton, A.M.I.Struct.E., A.M.I.C.E., c/o Dorman Long (Africa) Ltd., P.O. Box 932, Durban.

Cape Section Hon. Secretary : R. F. Norris, A.M.I.Struct.E., African Guarantee Building, 8, St. George's Street, Cape Town.

EAST AFRICAN SECTION

Chairman : R. A. Sutcliffe, M.I.Struct.E.

Hon. Secretary : K. C. Davey, A.M.I.Struct.E., P.O. Box 30079, Nairobi, Kenya.

NIGERIAN SECTION

Chairman : J. W. Henderson, E.R.D., B.Sc., M.I.Struct.E., M.I.C.E.

Hon. Secretary : A. Brimer, A.M.I.Struct.E., Brimer, Andrews & Nachshen, Private Bag Mail 2295, Lagos, Nigeria.

SINGAPORE AND FEDERATION OF MALAYA SECTION

Chairman : T. F. Lee, B.Sc.

Hon. Secretary : W. N. Cursiter, B.Sc., A.M.I.Struct.E., A.M.I.C.E., c/o Redpath Brown & Co. Ltd., P.O. Box 648, Singapore.

ADDITIONS TO THE LIBRARY

BOULTON, E. H. B. and JAY, B. A. *Building Timbers, 2nd Edition.* London, 1945.

British Petroleum Equipment, 1959/60 *Edition.* London, 1959.

BUDGEN, N. F. *Aluminium and Its Alloys.* London, 1947.

CASSIE, W. F. and NAPPER, J. H. *Structure in Building, 2nd Edition.* London, 1958.

CLARK, D. *Plane and Geodetic Surveying*, Vol. 1. *Plane Surveying, 5th Edition.* London, 1958.

D.S.I.R. *Road Research Laboratory. Soil Mechanics for Engineers.* London, 1952.

FRANCIS, J. R. D. *A Textbook of Fluid Mechanics for Engineering Students.* London, 1958.

GEARY, A., LOWRY, H. V. and HAYDEN, H. A. *Mathematics for Higher National Certificate.* London, 1957.

GIBSON, A. H. *Hydraulics and its Applications, 5th Edition.* London, 1952

GRAY, W. S. *Reinforced Concrete Water Towers, Bunkers, Silos & Gantries. 3rd Edition*, 1953.

HARTREE, D. R. *Numerical Analysis.* Oxford, 1958.

HAWRANEK, A. and STEINHARDT, O. *Theorie und Berechnung der Stahlbrücken.* Berlin/Göttingen/Heidelberg, 1958.

LEGAT, A. W., DUNN, G. and FAIRHURST, W. A. *Design and Construction of Reinforced Concrete Bridges, Revised Edition*, London, 1957.

LOWRY, H. V. and HAYDEN, H. A. *Advanced Mathematics for Technical Students*, Part II, *2nd Edition.* London, 1957.

MARSHALL, W. T. *Solution of Problems in Structures.* London, 1958.

MAXWELL-COOK, J. C. *Civil Engineering Contracts Organisation.* London, 1959. Presented by Mr. F. T. Bunclark.

REYNOLDS, T. J. and KENT, L. E. *Introduction to Structural Mechanics, 3rd Edition.* London, 1955.

ROLLASON, E. C. *Metallurgy for Engineers. 2nd Edition.* London, 1949.

TRIGG, C. F. *An Engineer's Approach to Corrosion.* London, 1952.

WRIGHT, FRANK LLOYD. *A Testament.* New York & London, 1957. Presented by Mr. G. Dickinson.

Book Reviews

Reinforced Concrete Simply Explained, 5th Edition, by Oscar Faber, revised by John Faber. (London : Oxford University Press, 1959). $8\frac{1}{2}$ in. × $5\frac{1}{2}$ in., 88 plus xii pp. 12s. 6d.

The fifth edition of this useful little book, which deals in a simple manner with reinforced concrete for the benefit of readers with little technical knowledge, remains substantially as before. Changes have been made to bring the book in line with the latest Code of Practice C.P. 114 (1957), and there is some rearrangement of the subject matter to make the order of presentation more logical, particularly in the case of column design for which the whole of the text now appears in one chapter.

Advanced Structural Analysis, by S. F. Borg and J. J. Gennaro. (New York and London : D. Van Nostrand Company Inc., 1959). 9¼ in. × 6 in., 368 pp. plus xiii 56s. 6d.

Here is a new book from the United States, covering a field already well tilled by American authors. This one however starts on the usual lines and then breaks loose into fields of most interesting pasture.

The first four chapters cover the usual course in statically indeterminate structures commencing with deflection theory which is rightly considered fundamental and covering all the common methods used for the solution of continuous girders and rigid frames, the treatment is of necessity rather brief, but it is stimulating and the problems well chosen and some interesting mathematical methods are given. Slope deflection and moment distribution are of course given chapters to themselves, but it seems a pity that in a new book on this subject, room could not be found for some treatment of abbreviated methods of moment distribution such as Naylor's method, nor for the interesting methods due to Gaspar Kani, for it is in multi-storey and multi-bay frames that the traditional methods become so cumbersome.

From this point the remaining chapters cover elastic arches very fully, numerical methods of deflection analysis, torsion of non-circular sections, plastic limit design, slabs and shells, temperature effects in structures, and finally computer methods of analysis.

Much of this work does not usually appear in books of this kind and therefore it is the book's most valuable contribution. The treatment is in most cases brief, and further reading is essential, but the subject matter is excellently chosen and very stimulating.

Summing up, the book may be confidently recommended to advanced students in technical colleges and universities, and even to some practising engineers who will find much to interest them. P.M.G.

Dock and Harbour Engineering Vol. II. The Design of Harbours, by H. F. Cornick. (London : Charles Griffin & Co., Ltd., 1959) 11 in. × 8½ in., 344 plus xvi pp. £6 6s.

The second volume of this four-volume treatise, the first of which was reviewed in the February, 1959 issue of "The Structural Engineer," contains chapters 7-14.

After an introduction giving general observations and history, chapters follow on classification of harbours and general principles of design, with particular reference to the number and sizes of ships to be accommodated, general conditions governing choice of locality, and natural phenomena such as effect of tides, wave action, tidal currents, direction and intensity of wind, coastal changes, silting, etc., with examples of harbours, and submarine surveying.

The various types of breakwaters and pierheads, including numerous examples, are described and failures analysed in Chapter 11, and Chapter 12 is devoted to jetties, piers and landing stages, including information on the bearing power of piles and piling formulae, fender systems and pontoons, illustrated by important examples.

In conclusion there are chapters on entrance channels, with details of groynes, walls, revetments, etc., and on channel demarcation and moorings.

This is a well-produced and comprehensive treatise on the subject, containing well over one thousand illustrations, many consisting of full pages or folders each containing a number of diagrams, and including a bibliography at the end of each chapter.

Examples of the Design of Reinforced Concrete Buildings, 2nd Edition, by Charles E. Reynolds. (London : Concrete Publications, Ltd., 1959). 9 in. × 6in., 265 plus vi pp. 12s. 6d.

The tables, examples, and notation in this new edition are in accordance with the most recent British Standard Codes of Practice. The first part deals with design and includes more than sixty design tables, whilst the second part gives details of the design of a typical multiple-storey building, which has been planned to incorporate as many of the matters dealt with in the Codes as is practicable.

Among the new matter are revised bending-moment factors ; the load-factor method applied to the design of beams, slabs and columns subjected to bending ; concentrated loads on slabs spanning in one or in two directions ; and flat-slab floors as parts of a frame. The method of moment distribution applied to continuous beams, the design of load-carrying walls, stairs, and some types of foundations are included.

The second part includes twenty-one calculation sheets and seventeen pages of drawings showing the arrangement of, and reinforcement in, slabs, beams, columns, and other members. Alternative designs are given for beam-and-slab and flat-slab floors and for slabs spanning in two directions.

Pratique du Calcul des poutres continues par les méthodes analytiques et les lignes d'influence, by Paul Lheureux. (Paris : Eyrolles, 1958). 12¼ in. × 8¼ in., 224 pp. 3,410 Fr.

In the first part of this book, after a statement of the basic theory, various methods are given for the analysis of continuous beams having a constant moment of inertia, and this is followed by a short chapter on beams with variable moments of inertia. Influence lines and their application are dealt with in the second part, and the application of the theory to many practical examples is given in Part III. A short bibliography is also included in this volume which will be of value to structural engineers dealing with problems connected with continuous beams.

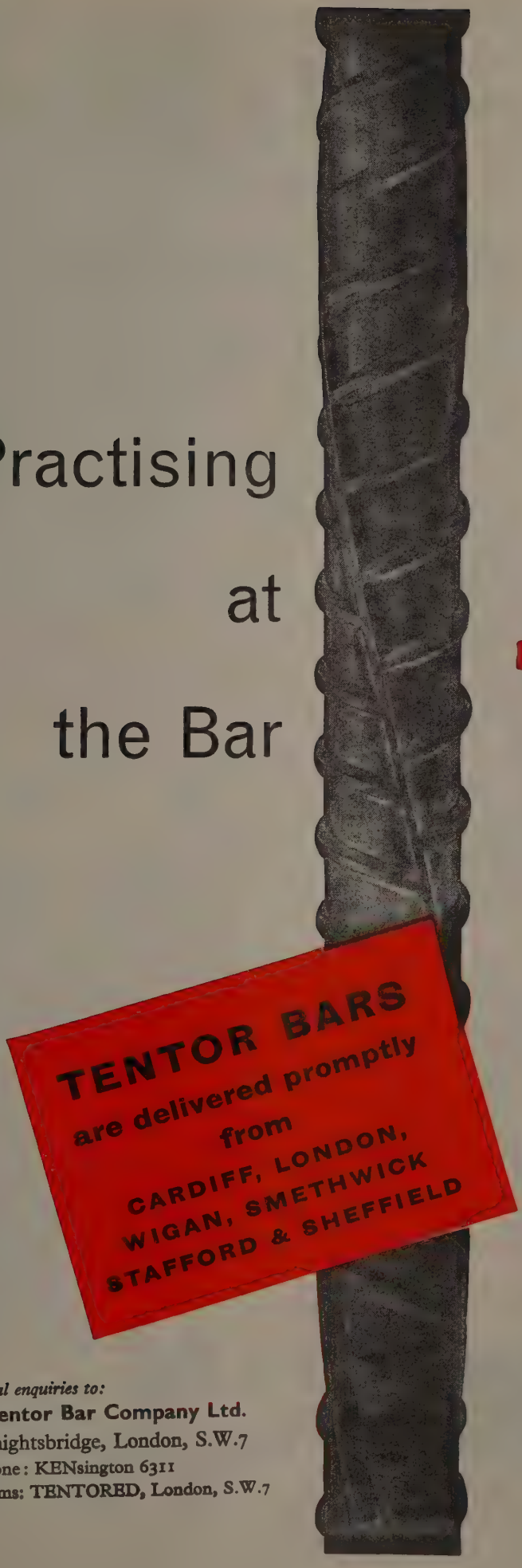
Composite Construction in Steel and Concrete, by I. M. Viest, R. S. Fountain and R. C. Singleton. (New York and London : McGraw-Hill, 1958). 9 in. × 6 in., 176 plus xv pp. 58s.

This book is a very welcome publication in these days when economy in design is so important. It deals with the design of floors in which steel girders act in conjunction with reinforced concrete slabs to form a composite tee-beam construction, and while the approach is centred on bridges, the application of the principle to buildings is incorporated in some detail.

From the Theory of Composite Design, design equations are developed and extended to continuous beams, determination of lengths of flange plates, and calculation of deflections. Various types of horizontal-shear connectors are dealt with at length. The book contains many worked examples, and numerous design aids including tables of moments of inertia of composite beams transformed to steel equivalent, of coefficients for horizontal-shear, and of shear connectors.

To the English engineer the American symbols and formulae are unfortunate ; moreover the girder sections in the tables are American, although a proportion of these correspond with the English Universal Beams. It is, perhaps, also a pity that the subject matter does not extend to cover concrete-encased stanchions. Notwithstanding these points the book is an excellent one which should be in the hands of every engineer who has maximum efficiency of design at heart. C.E.S.

Practising at the Bar



Pleading the case for Tentor Bar has its advantages.
Tentor is not just a citizen of credit and renown;
it possesses unimpeachable qualities; it has
a clean record; *it reinforces concrete extremely well,*
and is delivered promptly from six different places.
None of your forensic rhetoric for Tentor: Tentor
is vindicated absolutely on all counts.
In fact it cannot be too highly commended.
Tentor Bars for concrete reinforcement set high
standards in tensile and bond strength,
save up to 15% of the cost of Plain Rounds
require no hooks, and can be supplied to meet
contract requirements, cut or bent to specification,
in sizes from ¼″ to 1¼″.

Tentor Bars are supplied by the following companies and their branch offices :—

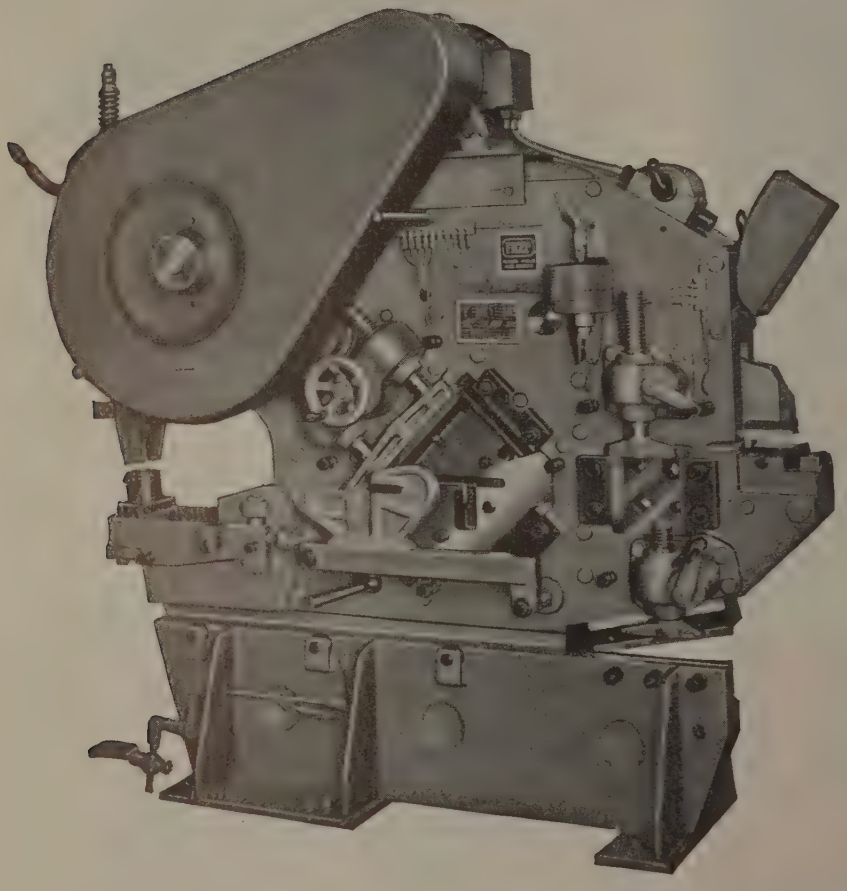
B.R.C. STEEL LTD.,
Silkmore Lane, Stafford. Stafford 444
G.K.N. REINFORCEMENTS LTD.,
197 Knightsbridge, London, S.W.7. KENsington 6311
McCALL & CO. (SHEFFIELD) LTD.,
P.O. Box 41, Sheffield. Rotherham 2076
STEEL, PEECH & TOZER, LTD.,
Branch of The United Steel Companies Ltd.,
The Ickles, Sheffield. Sheffield 41011

TENTOR BARS *Registered Trade Mark*

Technical enquiries to:
The Tentor Bar Company Ltd.
197 Knightsbridge, London, S.W.7
Telephone: KENsington 6311
Telegrams: TENTORED, London, S.W.7

FICEP

★ UNIVERSAL PUNCHING, SHEARING, CROPPING & NOTCHING MACHINES



MODEL "STANDARD"

Built in five sizes with shearing capacities from $\frac{3}{8}$" to 1". The operations are contained in one compact and sturdy power driven unit with separate working positions for punching, shearing, angle and section cropping, bar cropping, and notching.

Alternative models, without punching motion and single purpose punching machine.

Stand No. 55 at the Machine Tool Exibition, Olympia in June.

OTHER MACHINES IN THE "FICEP" RANGE

Hand lever operated combination shears, performing the function of a power operated machine.

Portable Bar Shears, Model BETON, in 4 sizes, for Rounds, Squares and Flats.

Alligator Shears, in four sizes with crushing jaws on three larger sizes.

SOLE DISTRIBUTORS IN THE UNITED KINGDOM

THOS. W. WARD LTD

ALBION WORKS, SHEFFIELD · 'PHONE: 26311 (22 lines)

LONDON OFFICE: BRETTENHAM HOUSE, LANCASTER PLACE, STRAND, W.C.2. PHONE: TEM 1515 (12 lines)

S.M.26

Larssen piling in use in the Pymmes Brook Improvement Scheme for the Lee Conservancy Catchment Board. Engineer: N. Medrington, A.M.I.C.E., M.I.W.E. Contractors: Howard Farrow Ltd.

ROLLED EXCLUSIVELY IN THE UNITED KINGDOM BY

South Durham

Larssen piling offers the maximum resistance to corrosion, hence its universal application to all forms of river frontage, quay wall, dock and harbour construction.

Results of the series of 15-year tests carried out by the Sea Action Committee of the Institution of Civil Engineers combined with the recorded results of examinations of piling structures which have been in use for periods up to 50 years and more indicate that the useful life of a Larssen piling structure can be safely estimated on the basis of an average annual corrosion rate of 0.003 inches per year in sea water and 0.002 inches per year in fresh water.

These figures apply to piles rolled from steel to B.S. No. 15. By employing either "Carfleco-Noncorr" copper-bearing steel or "Atlantes" high tensile rust-resisting steel, the life of Larssen piling structures can be considerably prolonged.

SOUTH DURHAM STEEL AND IRON COMPANY LIMITED

Central Sales Office: CARGO FLEET IRON WORKS, MIDDLESBROUGH, YORKS

Telephone: Middlesbrough 46311 (13 lines). Telex: 58551

London Office: SHELL-MEX HOUSE, STRAND, W.C.2.
Telephone: COVent Garden 1181/6. Telex: 25429

To assist engineers and contractors in the development of projects involving the use of Larssen piling, the South Durham Steel and Iron Company Limited maintains a permanent staff of designers for consultation and the design of Larssen piling structures.

For a first-class job—use

LARSSEN STEEL SHEET PILING

THE OUTSTANDING CIVIL ENGINEERING MATERIAL

Photographs by courtesy of : Corporation of London, New Public Cleansing Depot ● City Engineer : Francis J. Forty, O.B.E., B.Sc., M.I.C.E. ● Consulting Engineers : Mott, Hay & Anderson ● Contractors : Howard Farrow Ltd.

ON THIS TOUGH THAMES-SIDE JOB . . .

Howard Farrow Ltd. rely on "BROOMWADE" RB 770B BREAKERS

The construction of an open barge dock for the Corporation of London was preceded by site clearance of exceptional difficulty.
On site between Cannon Street Station and Southwark Bridge, the breaking up of a maze of heavily reinforced concrete foundations became the major task; blasting was impracticable but a team of hard hitting "BROOMWADE" RB 770B Breakers powered by a WR 630 Rotary Compressor rapidly smashed through the seemingly impregnable mass.
Whatever the task "BROOMWADE" Air Compressors and Pneumatic Tools fully meet the contractor's demand for

ECONOMY, EFFICIENCY and RELIABILITY

"BROOMWADE"

AIR COMPRESSORS & PNEUMATIC TOOLS

YOUR BEST INVESTMENT

BROOM & WADE LTD., P.O. Box No. 7, HIGH WYCOMBE, ENGLAND. Telephone: High Wycombe 1630 (10 lines) Telegrams: "Broom," High Wycombe (Telex)

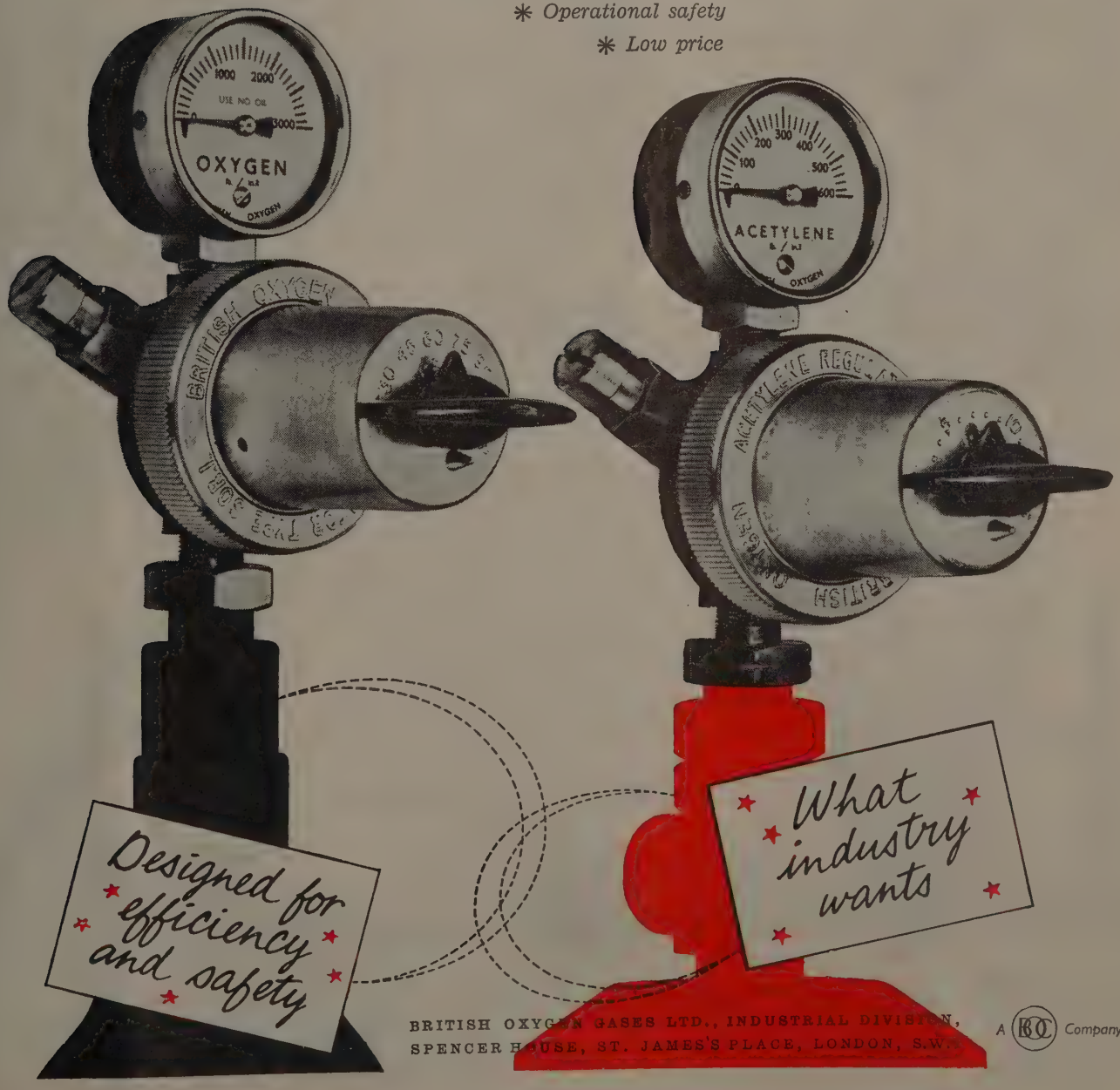
663 SAS

a DOUBLE event from British Oxygen

Two new 7 star Single Stage Regulators

Here are two brand new single stage regulators that are ideal for heavy industry. They are the new S.O.R.1, and S.A.R.1, and they have *all* the following *7-star* features:

✱ *Simple design* ✱ *Operational efficiency* ✱ *Robust construction*
✱ *Light weight* ✱ *Easy maintenance*
✱ *Operational safety*
✱ *Low price*



BRITISH OXYGEN GASES LTD., INDUSTRIAL DIVISION, SPENCER HOUSE, ST. JAMES'S PLACE, LONDON, S.W.1.

A BOC Company

BUCKLERSBURY HOUSE STANDS ON 3,500 BORED PILES

This important Office Building in the City of London, 17 storeys high including the basement floors, is supported on Cementation Bored Piles. Approximately 3,500 were constructed well within the contract time despite the fact that delays were unavoidably occasioned by the deliberations on the fate of the Mithras Temple discovered on the site and other major difficulties inevitable on such a large site.

The construction of a surrounding wall to retain the adjoining Queen Victoria Street, Cannon Street and Bucklersbury was greatly facilitated by the use of our bored piles.

The close proximity of important buildings including the Mansion House and services such as the Underground Railway made it necessary to reduce noise, vibration etc., to an absolute minimum.

The CEMENTATION COMPANY LIMITED

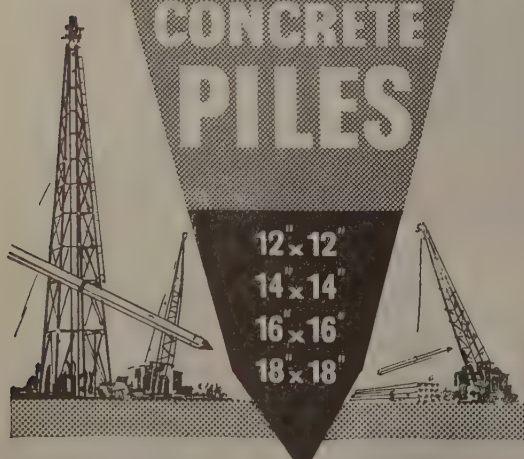
HEAD OFFICE: 20, ALBERT EMBANKMENT, LONDON, S.E.11. Tel: RELiance 7654

WORKS & OFFICES: BENTLEY WORKS, DONCASTER · Tel: 54175 & 54136

It is safest to specify STENT!

STENT PRECAST CONCRETE PILES

12"x12"
14"x14"
16"x16"
18"x18"



Preferred by constructional engineers for their unchanging supremacy, Stent Precast Concrete Piles have proved their qualities wherever used.

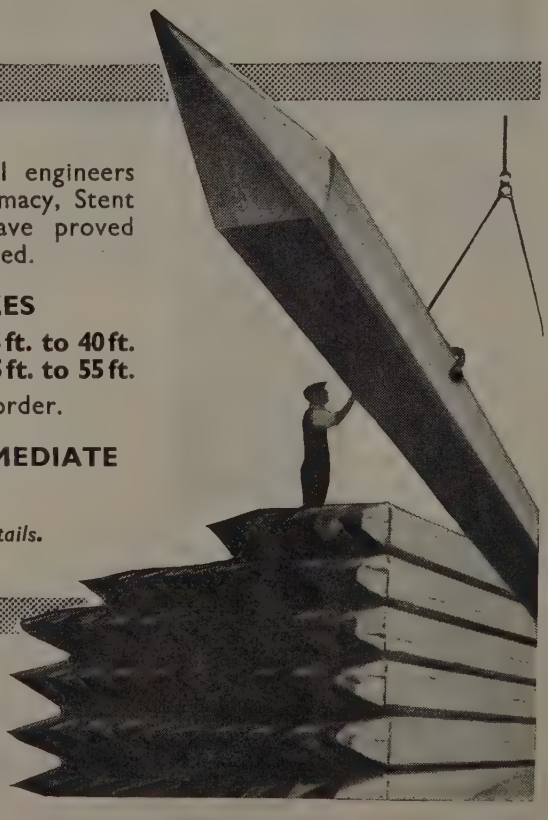
STANDARD SIZES

12 in. x 12 in. in lengths 15 ft. to 40 ft.
14 in. x 14 in. in lengths 15 ft. to 55 ft.

Other sizes made to order.

AVAILABLE FOR IMMEDIATE DELIVERY

May we forward full details.



STENT PRECAST CONCRETE LTD.

Chequers Lane, Dagenham Dock, Essex. Dominion 0971

SUPER SNOWCEM

WATERPROOF CEMENT PAINT

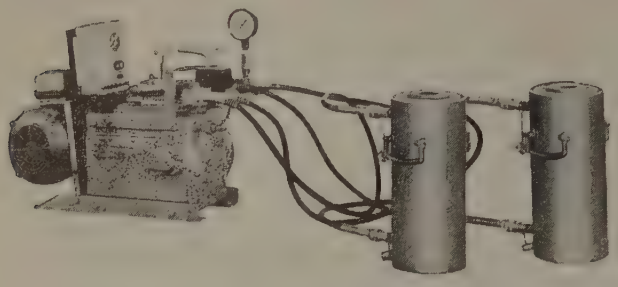
makes a well-designed house even better

Super Snowcem—like many of the walls it decorates and protects—has a base of cement that sets rock hard. That's why architects specify Super Snowcem. They know that when it comes to the painting of outside walls, no paint in the world does the job so effectively, so economically as Super Snowcem.

Write for free booklet and shade card to:
SNOWCEM SERVICE, 14 TOTHILL STREET, LONDON, S.W.1.

T.160a

Several remote Control Rams can be operated by motorised or hand pump, with Gauges to determine loads, and Shut-off valves to control the lift of each ram. Ideal for Bridge Lifting etc.



Self-contained and remote control CENTRE HOLE models up to 300 tons capacity for pushing or pulling through the centre of the Jack, without torque.

Simplex offers the largest range in the World for mechanical and hydraulic jacks. They are noted for quality, ease of operation and light-weight. Large quantities purchased before the war are still in use.

Full details sent on request

The Equipment & Engineering Co. Ltd.

2 & 3 Norfolk Street, London, W.C.2 Tel: Temple Bar 1088

SIMPLEX

JACKS

for every conceivable use including

STRUCTURAL STEEL ERECTING

PRE-STRESSING & POST-TENSIONING CONCRETE

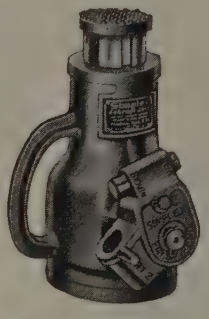
BRIDGE BUILDING & BRIDGE LIFTING

CABLE & ROPE TENSIONING

HEAVY MACHINERY MAINTENANCE

PIPE PUSHING

TRACK MAINTENANCE



Ball bearing Journal Jacks (bevel geared) up to 50 tons capacity

THE SAFETY STEEL FLOORPLATE

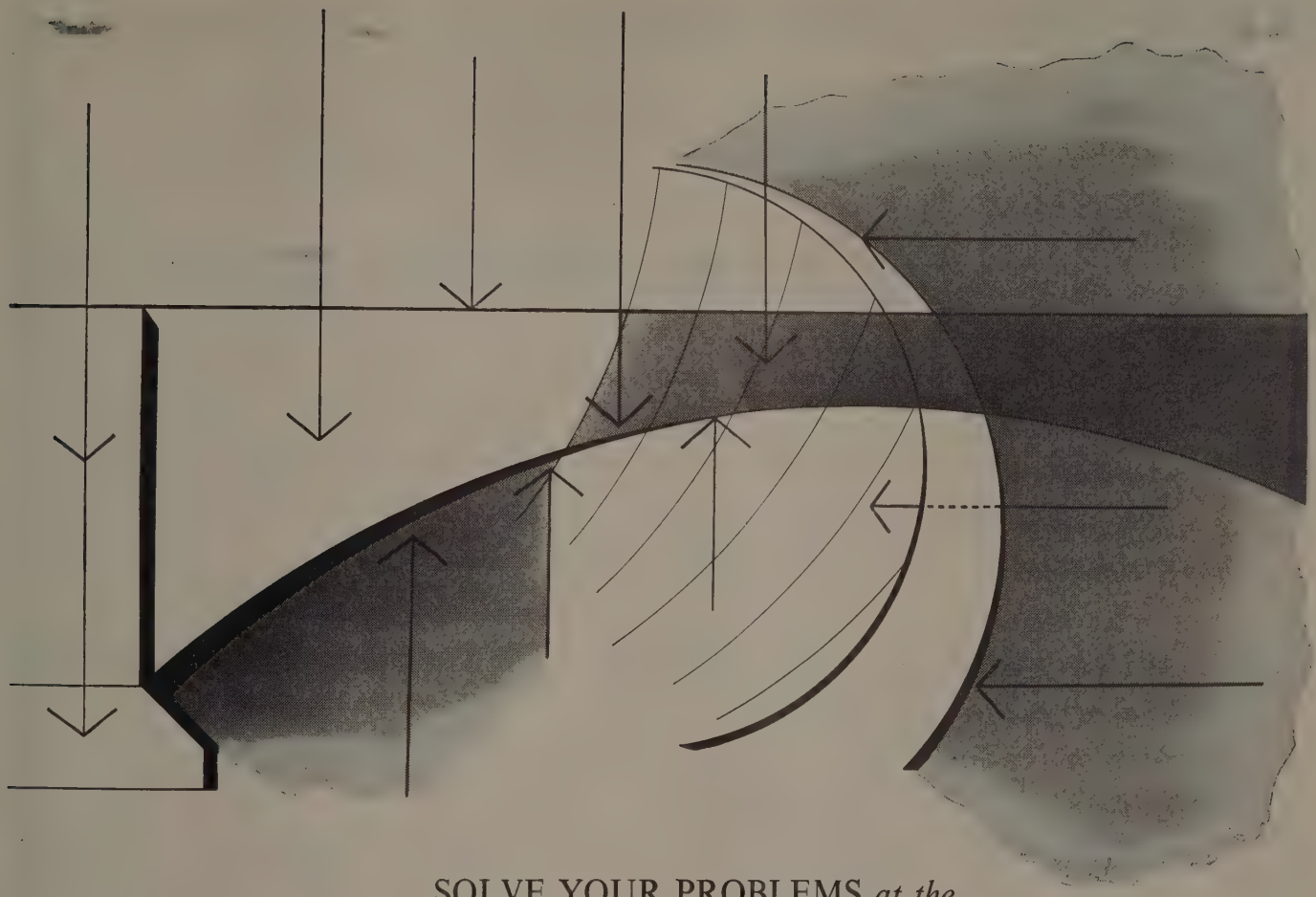
- Safe and positive grip in all directions.
- Free drainage and easy cleaning.
- Fabrication to your requirements.

CONSETT IRON COMPANY LIMITED.

Telephone: Consett 341 (12 lines)

CONSETT, County Durham.

Telegrams: Steel, Phone, Consett.



SOLVE YOUR PROBLEMS *at the*

Stantec-Zebra

Electronic Digital Computer Service Centres

Some of the problems being handled by the 'Zebra'

Empirical and theoretical studies of dam and bridge testing

Processing of empirical data resulting from photographic studies and aerial surveys

Bridge design

Our experts would be glad to discuss your problems and, if requirements do **not** *warrant the purchase of a computer, we suggest you consider the facilities of our Computer Service Centres.*

A double input-output Stantec-Zebra Computer

STC are Britain's biggest exporters of digital computers

ELECTRONIC SYSTEMS GROUP

Standard Telephones and Cables Limited

Registered Office: Connaught House, Aldwych, London, W.C.2

INFORMATION PROCESSING DIVISION: CORPORATION ROAD · NEWPORT · MON.

60/2L

SOIL MECHANICS

GEOPHYSICAL SURVEYS
SITE INVESTIGATIONS
SOIL MECHANICS TESTING

WATER PROBLEMS

GEOPHYSICAL SURVEYS
WATER WELL DRILLING
(By Rotary Air, Mud Flush, Shot Cable and Percussion Systems)
PUMPING PLANT INSTALLATION
AND MAINTENANCE

LE GRAND ADSCO LIMITED

(Le Grand Sutcliff & Gell Ltd., and
Associated Drilling and Supply Co. (Overseas) Ltd.)

LE GRAND

Write for Illustrated Brochure.

Le Grand Adsco Ltd.
The Green, Southall, Middx.
Tel. : SOUthall 2211.

Iddesleigh House
Caxton Street, London, S.W.1.
Tel. : ABBey 3242.

PARCHMORE

Engineering & Precision Ltd.

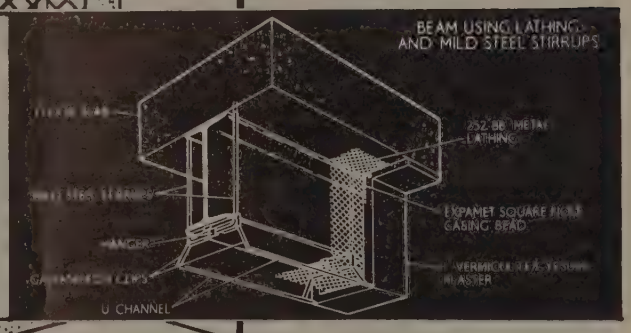
Telephone: THORNTON HEATH 1491

Manufacturers of

Special Purpose Machinery and
General Engineers

507 LONDON ROAD, THORNTON HEATH
SURREY

When it comes to fire-cladding steel joists



EXPANDED METAL IS BETTER IS CHEAPER*

Compare Expanded Metal lathing and lightweight plaster fire protection with conventional methods. With Expanded Metal techniques you save up to 110 lbs. dead weight per foot length on a steel beam. No waiting for shuttering either and fire-cladding and interior finish is one operation.

* *This is a major advance in British Building.* Write for details of the part played in it by Expamet Expanded Metal.

LOOK AROUND YOU and see how lighter steel structures are possible by using these weight saving techniques. To save time and trouble call in our Construction Department who supply and fix plaster backgrounds.

Expamet

THE EXPANDED METAL COMPANY LIMITED, 16 Caxton Street, London, S.W.1. Phone: ABBey 7766 · Also at: Aberdeen · Belfast · Birmingham · Cardiff · Dublin · Exeter · Glasgow · Leeds · Manchester · West Hartlepool · The Expanded Metal Company of Canada Limited, Annacis Industrial Estate, Vancouver, Canada.

Agents in every country throughout the free world.

PRECAST
CONCRETE
ENGINEERS

The BELCON service is designed to meet the dual requirements of the industrial developer and the Architect or Consulting Engineer.

A basic range of single storey concrete frames is available up to 50 feet span. Other requirements can be met by special design.

Design · Construction · Site Preparation

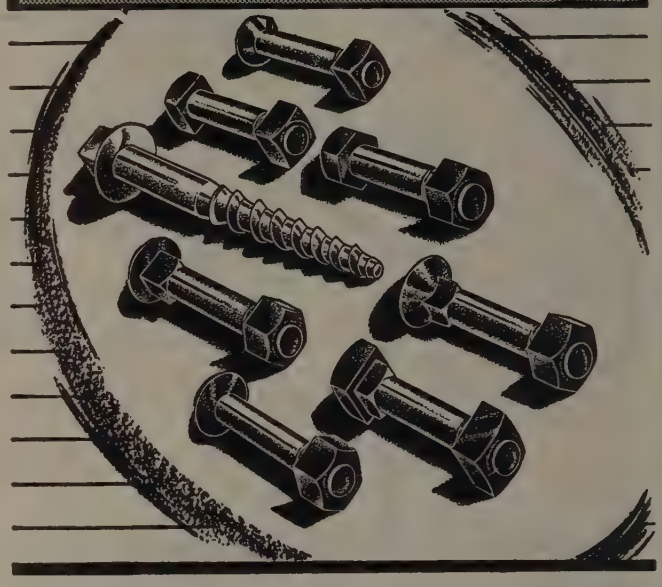
BELCON

BELL & WEBSTER LTD

ESSEX ROAD · HODDESDON · HERTFORDSHIRE
TELEPHONE HODDESDON 4421

CONCRETE FRAMES • MULTIPLE GARAGES • SHEDS AND SHELTERS
FENCING • PYLONS • CABLES • WINDOW FRAMES

COOPER
NUTS and BOLTS



George Cooper & Sons
PROPRIETORS THOS. W. WARD LTD.
EFFINGHAM NUT & BOLT WORKS
SHEFFIELD
Phone : 41026 Grams : COOPER

C.7

A RECENT ADDITION
TO THE FAMOUS
PITMAN
LIST

SURVEYING

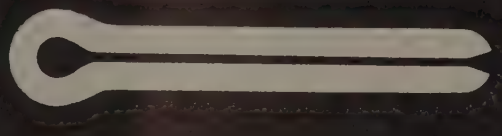
By
A. Bannister, M.C., B.Sc.(Hons.), etc.,
and
E. S. Raymond, B.Sc.(Tech.) (Hons.), etc.

This book provides a direct approach to the basic problems involved in the various branches of Surveying. The principles underlying the surveyor's art are carefully established, and the student is introduced to modern instruments and techniques. An important book for all who are studying for the following examinations: H.N.C. and Diploma in Civil and Structural Engineering and in Building; Inst. of Civil Engineers, Part II; R.I.C.S. and similar professional examinations; Diploma in Technology and Degrees in Engineering. Engineering Degree Series. Price 45/- net.

From all booksellers

PITMAN Parker St., Kingsway, London, W.C.2

What is
the cheapest
and simplest way
of fixing
this...



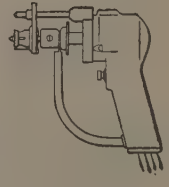
to this?...

When both are metal—the answer is almost invariably stud welding. The cost may be as little as one fifth of, for instance, the cost of drilling and tapping. The time an even smaller fraction. And stud welding is far stronger than any alternative method and absolutely permanent.

Stud welding is speeding up production and lowering costs in an immense range of industries from shipbuilding to domestic equipment. Attachments may be of almost any shape. A talk with our Engineers perhaps, followed by a demonstration, will be worth your while.

Crompton Parkinson

STUD WELDING



CP ELECTRICAL EQUIPMENT

CROMPTON PARKINSON (STUD WELDING) LIMITED
1-3 Brixton Road, London, S.W.9. Telephone: Reliance 7676

CONCRETE ROADS FIRST
because
CONCRETE ROADS LAST

Glossop Road, Sheffield.—City Engineer, R. Nicholas, C.B.E., M.I.C.E., etc., R.C. slab reinforced with 'Matobar' fabric.

McCALL & COMPANY (SHEFFIELD) LIMITED

TEMPLEBOROUGH SHEFFIELD P.O. BOX 41

Telephone: ROTHERHAM 2076 (P.B. Ex. 8 lines)

LONDON: **SLOANE 0428** ***PORTSMOUTH:*** **COSHAM 78702**

BIRMINGHAM: **ACOCKS GREEN 0229**

McCALL & COMPANY (SHEFFIELD) LIMITED
McCALLS MACALLOY LIMITED
PRECISION ROOFS LIMITED

McCALLS MACALLOY AFRICA (PROPRIETARY) LIMITED
McCALLS MACALLOY (AUSTRALIA) PTY. LIMITED
McCALLS MACALLOY (CANADA) LIMITED

SRB 96

OFFICIAL APPOINTMENTS

AIR Ministry Works Designs Branch requires in London, Structural Engineering Designer Draughtsmen for reinforced concrete or structural steelwork of all types. Applicants must have adequate training and several years' experience. Some site experience and possession of recognised technical qualification an advantage. Financial assistance and time off may be allowed for recognised courses of study. Promotion and pension prospects. Five day week with 18 working days leave per year initially. Salary for Grade III ranges from £680 (at age 25) to £900 p.a. Commencing salary dependent on age, qualifications and experience. Also vacancies in higher grade for suitably qualified candidates on range from £895 to £1,055 p.a. Applicants, who must be natural born British subjects, should write to Air Ministry, W.G.c, Lagon House, Theobalds Road, London, W.C.1, or to any Employment Exchange (quoting Order No. Kings Cross 3745), giving age, details of training, qualifications, full particulars of former posts held and copies of any testimonials. Candidates selected will normally be interviewed in London and certain expenses reimbursed.

BRITISH RAILWAYS
LONDON MIDLAND REGION

have employment at Euston for

STRUCTURAL ENGINEER
(Reference 90)

to undertake design in steel, reinforced and pre-stressed concrete, capable of calculating statically indeterminate structures. Must have a University degree and experience in similar work. Post Graduate studies and membership of the Institution of Civil Engineers or the Institution of Structural Engineers will be an advantage. Salary range £1,150 to £1,315 per annum.

STRUCTURAL ENGINEERS
(Reference 91)

Should be capable of the design and detailing of railway structures in steel, reinforced and pre-stressed concrete. Membership of the Institution of Civil Engineers or the Institution of Structural Engineers desirable.
Salary range £833 to £985 per annum.

ENGINEERING ASSISTANTS
(Reference 92)

Should have experience in rail track layouts and general civil engineering work. Should be capable of preparing schemes on own initiative.
Salary range £833 to £985 per annum.
Superannuation Scheme, five-day week, residential and other travelling facilities. Applications quoting reference and giving details of age, experience and educational background to :—

Chief Civil Engineer,
British Railways, London Midland Region,
5a, Euston Grove,
London, N.W.1.

CIVIL Engineering Appointment, McMaster University—The Department of Civil Engineering and Engineering Mechanics solicits applications for a staff position in a new school with a stimulating research environment. The candidate should possess a graduate degree (preferably the doctorate) based on specialization in structures, and some experience in lecturing and research direction. Duties will include undergraduate and graduate instruction, and good research facilities are available. Appointment will be made at the rank of assistant or associate professor, depending upon qualifications and experience. Enquiries and the names of three references should be addressed to : N. E. Wilson, A.M.I.Struct.E., Civil Engineering, McMaster University, Hamilton, Ontario, Canada.

IMPERIAL COLLEGE OF SCIENCE AND TECHNOLOGY

Bursaries in Concrete Technology

Bursaries of £460-£760 according to experience are available for Session 1960-61. Candidates must hold a degree in engineering and have a good knowledge of the theory of structures. Full information from the Registrar, Imperial College, London, S.W.7. Closing date, June 1st, 1960.

SURREY COUNTY COUNCIL

Applications invited for appointment of Assistant Structural Engineers, Special Grade (£785-£1,070 p.a. plus £30 p.a. London Allowance). This grade is particularly suitable for newly qualified Assistants. Must be qualified Civil or Structural Engineer, experienced in design and detailing in steel and/or reinforced concrete.
Candidates will be appointed at the appropriate point within the scale according to age and ability.
Full details, present salary and three copy testimonials to County Architect, County Hall, Kingston, as soon as possible.

THE UNIVERSITY OF SOUTHAMPTON. Applications are invited for the post of Reader in Structural Engineering newly established in the Department of Civil Engineering with the support of the Institution of Structural Engineers. Candidates should have considerable experience in structural engineering research and should be capable of promoting a school of research in their own specialities. Salary Scale : £1,450 by £75 to £2,125 by £25 to £2,150. Initial salary will depend on qualifications and experience. Further particulars should be obtained from the Secretary and Registrar to whom applications (14 copies from United Kingdom applicants) should be sent not later than 15 March, 1960.

CLASSIFIED ADVERTISEMENTS

From January, 1958, the rate per word will be increased from 8d. to 1/-

	2 in.	Semi Display	£6 0s. 0d.
RATES	3 in.	„	£8 10s. 0d.
	4 in.	„	£11 0s. 0d.

SITUATIONS VACANT

AIC **Executive Selection Service**

STRUCTURAL STEEL DESIGNER

An expanding firm of structural Steelwork Engineers in the West Riding of Yorkshire invite applications from experienced and qualified engineers for the above post. Candidates must have a sound knowledge of competitive design in all types of industrial and commercial buildings. Pension scheme, annual bonus scheme and good salary prospects. Assistance with housing if required.

Applications, giving details of education and experience, in confidence, to :

Appointment No. 67
Associated Industrial Consultants Limited,
Bush House, Aldwych, London, W.C.2.

ASSISTANT Structural Engineer conversant with Reinforced Concrete work required for London Consulting Civil Engineers. Minimum qualification H.N.C. Write stating age, experience and salary. Box No. 9076, STRUCTURAL ENGINEER, 43a, Streatham Hill, S.W.2.

WINTER & WORSFOLD, LTD.

respectfully offer you a **Design Service** *to plan and execute the typography and design of*

Books · Advertising matter and Commercial Printing

Winter & Worsfold, Ltd., East Down Works, 29 Dermody Rd., Lewisham, S.E.13

Telephone: Lee Green 3488

SITUATIONS VACANT—continued

BIRMINGHAM Consulting Engineers require qualified Assistants and Draughtsmen for work on commercial, industrial and municipal buildings in steel and concrete. Write to James-Carrington & Partners, 19, Masshouse Lane, Birmingham, 5.

CHARTERED Structural Engineer required for progressive and expanding R.C. Design office of medium size in S.W. London. Experienced man familiar with current codes and modern techniques to take charge of small section. Permanent, superannuated post. Full details experience, age, salary, to Box No. DL 9044, c/o White's, 72, Fleet Street, London, E.C.4.

DESIGNERS and/or Detailers R.C. (2) required for West End Consulting Engineer's office. Knowledge of steel work an advantage. Pleasant and informal working conditions. Salary £750-£950 according to ability. Write Box 9079, STRUCTURAL ENGINEER, 43a, Streatham Hill, S.W.2.

EXPERIENCED Designers and Draughtsmen in Reinforced Concrete required by Consulting Engineers in Golders Green. Progressive permanent position. Five day week, Pension scheme. Box No. 9078, STRUCTURAL ENGINEER, 43a, Streatham Hill, S.W.2.

NORTH West Structural Engineering Company require Chief Designer to deal with interesting and varied work. Good remuneration and working conditions. Applicants should be over 30 years of age, experienced in all types of structures and platework. Assistance will be given on travel and removal expenses. All staff advised of this advertisement. Write, in confidence, giving full details of age, experience, and salary required to Box No. 9074, STRUCTURAL ENGINEER, 43a, Streatham Hill, S.W.2.

REINFORCED Concrete Specialist firm requires Designer/Detailers. Interesting and varied work. Some previous experience. Write Chief Engineer, Caxton Reinforced Concrete Limited, 45, Bedford Row, W.C.1.

A progressive, medium-sized Company of Structural Engineers situated in the North-West desire to appoint an

ERECTION MANAGER

The appointment offers a challenging and interesting career to a keen, energetic man in the age group 30-45 years. The Manager will be based on Head Office but will travel in the United Kingdom, a suitable car being provided.

Applicants should be engineers of A.M.I.Struct.E. standard or equivalent and must be capable of :

(1) Planning and organising all erection work undertaken by the Company.

(2) Controlling an Erection Staff of Foremen and erectors exceeding 100 in the aggregate, and maintaining a high standard of workmanship and safety.

(3) Estimating for erection of Structural steelwork contracts up to 3,000 tons, and for a variety of welded platework.

(4) Advising on the purchase of capital equipment.

(5) Providing a high standard of service to the Company's clients.

An attractive salary and pension rights will be offered to the suitable applicant. Applications, which will be treated in strict confidence, should contain full details of age, qualifications, if any, and past experience and should be addressed to :—

Managing Director.
Box No. 9077

SITUATIONS VACANT—continued

CLASSIFIED ADVERTISEMENTS

From January, 1958, the rate per word will be increased from 8d. to 1/-

	2 in.	SEMI DISPLAY	£6 0s. 0d.
RATES	3 in.	,,	£8 10s. 0d.
	4 in.	,,	£11 0s. 0d.

REINFORCED CONCRETE

Applications are invited for the following progressive and permanent appointments to our staff for a large and varied programme of reinforced and prestressed concrete work :

(a) Design Engineers.
Chartered Structural or Civil Engineers with several years' experience in design, and a good knowledge of structural theory. Quick, accurate and original designers, capable of working without supervision, preparing outline scheme drawings and estimating quantities for in situ and precast concrete structures.

(b) Designer-Detailers.
Capable of quick, accurate design and detailing from outline schemes.

Excellent working conditions in new offices near Manchester, good salaries, plus annual bonus ; superannuation ; three weeks' holiday. Written applications to :—

Matthews & Mumby Limited,
Oldham Street,
Denton, Manchester.

REINFORCED Concrete Designer—Detailers required by leading Manchester Designers/Contractors engaged in all types of Reinforced, Prestressed, In situ and Precast Structures. Successful applicants will work in a small Drawing Office team under qualified Engineers where responsible initiative is encouraged. Write for interview, stating age and experience to, Fram Reinforced Concrete Co. Ltd., (Ref. S.W.S.), 165, Plymouth Grove, Manchester, or phone ARDwick 4521.

REINFORCED Concrete Specialist Firm requires Designer/Detailers. Interesting and varied work, luncheon vouchers, etc. Only experienced men need apply.—Write The Reinforced Concrete Steel Co., Ltd., 54, Victoria Street, S.W.1.

STRUCTURAL or Civil Engineer with experience of bulk handling of granular materials required to take charge of rapidly expanding department engaged in construction of steel bulk storage plants. Exceptional opportunity for man with leadership, administrative ability and drive. Age 30 to 40. Salary £1,200 minimum plus share of profits. Pension scheme. Condar Engineering Co. Ltd., Winchester.

SIMON-CARVES LTD.,

have a vacancy in their Building & Civil Engineering Dept., for a

FORMWORK DESIGNER/DETAILER

Applicants must have H.N.C. (Struct. or Mech.) or an equivalent standard of knowledge and wide experience of design and application of formwork structures for industrial and general civil engineering work. The post is permanent and pensionable and offers good prospects in an expanding department.

Starting salary up to £1,000 depending on experience and qualifications. Send brief relevant details to Staff and Training Division, **SIMON-CARVES LTD,**. Cheadle Heath, Stockport, Cheshire, quoting Ref. ZR. 49.

Truscon

in 1960

Truscon Drawing offices are now busier than ever, and interesting, challenging schemes of great variety are arriving at our office every day. This means that our reinforced concrete design staff, which over the years has been steadily growing, now needs the support of extra men, and, essentially, men of the right character and quality.

We hope that these men will help to maintain Truscon's own tradition of quality—and this applies *both* to construction *and* design. Indeed it may be that the early collaboration between our design and construction staff together with the constant interchange of information between office and site which an organisation such as Truscon permits, will of itself prove an attraction to the ambitious and imaginative, yet experienced, men we are seeking for our design offices.

The following positions are vacant:

London

2 reinforced concrete design engineers, with first-class experience of both project schemes and working drawings.

2 reinforced concrete detailers, again with first-class experience.

Harlow, Birmingham and Manchester

In each office: one designer and one detailer with similar qualifications to the above.

Please write initially to our Director-Engineering at Truscon House, Lower Marsh, London, S.E.1: giving brief details of your qualifications, positions held, experience gained and salaries earned. We are anxious to give applicants every opportunity to justify themselves at an interview, which will be in confidence and can, if necessary, be arranged outside business hours.

Jobs with Truscon are, subject to usual conditions of employment, permanent and secure yet progressive. Salaries are good, as are holidays and sick pay entitlement. We have a good pension scheme, with dependants' benefits, and a profit sharing scheme for staff. Promotion is by merit alone, and although we already have a number of mature young men holding down responsible posts, there's always room for more. **We shall be pleased to hear from *anyone* who would like to discuss the possibilities of joining Truscon in 1960.**

SITUATIONS VACANT—continued

R.C. DETAILERS required for London Professional Office. Experience of steelwork an advantage but not essential. The work is varied and offers scope for initiative. Five day week. Please apply giving full details and salary required to Farmer and Dark, Romney House, Tufton Street, Westminster, S.W.1.

STAFF required for Consulting Structural Engineer's office. Senior and Junior Engineers and Detailers, experienced in R.C. framed structures. Five day week. L.V. Apply in writing to Felix J. Samuely and Partners, 231-233, Gower Street, London, N.W.1., stating age, experience and salary required.

SOUTH London Consulting Engineers require experienced reinforced concrete engineers, designer/draughtsmen and detailers. Applicants should have a minimum experience of three years in position applied for. Salary commensurate with experience and ability. Luncheon vouchers and Five day week. Please write giving details of age, qualifications and experience to Messrs. Leonard & Grant, 344, South Lambeth Road, S.W.8.

SENIOR Structural Engineer required to take charge of a design office, specialising in Structural Steelwork of a varied nature. Applicant should be suitably qualified and between the ages of 30 and 40. The appointment carries seniority and good prospects of promotion. A salary commensurate with the applicant's experience and ability will be paid. Apply in confidence to the Technical Managing Director, Joseph Westwood & Co. Ltd., Bridge Builders & Constructional Engineers, Napier Yard, Millwall, London, E.14.

SMALL structural engineering office, W.C.1, area with extensive practice, requires additional assistants. Capable men from graduateship upwards required for high class miscellaneous work generally, foundations, dangerous structures, steel, concrete and timber, and able to work with minimum supervision. Reply in confidence with full particulars and salary required to Box 9071, STRUCTURAL ENGINEER, 43a, Streatham Hill, S.W.2.

STRUCTURAL ENGINEER

Applications are invited for the position of Production Manager in a medium sized Structural Engineering Works in the Glasgow Area. Applicants would require to take control of the drawing offices and workshops and be thoroughly conversant with the design of structures, and workshop practice. The position offers scope for a man with energy and initiative and is superannuated. Please reply in the first instance giving details of age and experience in chronological order together with salary expected to Box No. 865, Rex Publicity, 10, Clairmont Gardens, Glasgow, C.3. All replies will be treated in strict confidence.

STRUCTURAL and Civil Engineers require senior and intermediate designer-detailers experienced in either :

1. Reinforced Concrete or
2. Structural Steelwork.

Excellent opportunities in an expanding organization for the right men. Positions are pensionable and offer first class experience . Box No. 9075, STRUCTURAL ENGINEER, 43a, Streatham Hill, S.W.2.

SITUATIONS WANTED

A. GLOVER, B.Sc.Tech., A.M.I.Struct.E., eight years site and design office experience, will be interested to hear from consulting engineers requiring site representation on R.C. work in Bristol and the West. Box No. 9069, STRUCTURAL ENGINEER, 43a, Streatham Hill, S.W.2.

FOR HIRE

LATTICE Steel erection masts (light and heavy), 30 ft. to 150 ft. high, for immediate hire. Bellman's, 21, Hobart House, Grosvenor Place, S.W.1.

TUITION

GUARANTEED Coaching for Inst. Struct. Engrs., Inst. Civ. Engrs., Inst. Mun. Engrs., etc. Study at home under highly qualified tutors with most successful school. Also courses in all aspects of Building, Engineering, Draughtsmanship, etc.—Write for Free book—International Correspondence Schools, Intertext House (Dept. 423), Parkgate Road, S.W.11.

INDEX TO ADVERTISERS

	Page
Arroll, Sir William & Co. Ltd.	18 & 19
Associated Lead Manufacturers Co. Ltd.	20
Bannister, Walton & Co. Ltd.	7
Bell & Webster Ltd.	44
Booth. John & Sons (Bolton) Ltd.	17
B.R.C.	Cover IV
British Industrial Eng. Co. Ltd.	23
British Oxygen Gases Ltd.	4 & 37
Broom & Wade Ltd.	36
Cement Marketing Co. Ltd. (Snowcem)	39
Cementation Co. Ltd.	38
Consett Iron Co. Ltd.	40
Contract Journal	6
Crompton Parkinson Ltd.	45
Dawnays Ltd.	10
Demolition & Construction Co. Ltd.	2
Equipment & Engineering Co. Ltd.	40
Expanded Metal Co. Ltd.	43
Ficep	34
Fisher & Ludlow Ltd.	5
Frankipile Ltd.	21
G.K.N.	27
Ground Explorations Ltd.	16
Hill, Richard Ltd.	Cover II
Hotoplast Ltd.	11
Johnson, Richard & Nephew Ltd.	22
Kennedy, Allan & Co. Ltd.	28
Lafarge Aluminous Cement Co. Ltd.	Cover III & 29
Laing, John & Son Ltd.	32
Le Grand Adsco Ltd.	42
Lytag Ltd.	12
McCall & Co. (Sheffield) Ltd.	46
McKinney Foundations Ltd.	30
Pitman, Sir Isaac	44
Shell International Service	13
Simon-Carves Ltd.	3
Simplex Concrete Piles Ltd.	16
Smith John (Keighley) Ltd.	24
Skinningrove Iron Co. Ltd.	15
Skipwith Jones & Lomax Ltd.	42
South Durham Steel & Iron Co. Ltd.	35
Standard Telephones & Cables Ltd.	41
Stent Precast Concrete Co. Ltd.	38
Stramit Boards Ltd.	14
Tentor Bar Co. Ltd.	33
Terresearch Ltd.	26
Tileman & Co. Ltd.	25
Ward, Thomas W. Ltd.	1
Wood, Pritchett & Co. Ltd.	8 & 9

ALAG

A special aggregate for special purposes

New!*

ALAG is a synthetic aggregate which, when used with CIMENT FONDU, PRODUCES CONCRETE WITH THE FOLLOWING UNIQUE PROPERTIES:—

EXTREME RESISTANCE TO ABRASION

(Hardness of aggregate 7·5 MOHS. Cuts glass)

ENORMOUSLY HIGH STRENGTH IN A MATTER OF HOURS

(For example 12,000 lb per sq. inch at 24 hours and 16,000 lb per sq. inch at 7 days)

HIGH DENSITY

(167 lb per cu. ft air-dried—20 lb per cu. ft higher than normal).

HEAT-RESISTANT

(up to 1150/1200°C)

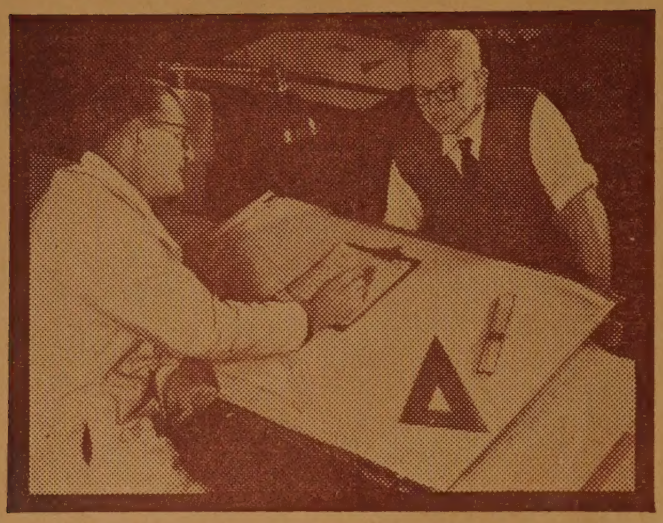
OR ALL ABOVE PROPERTIES COMBINED

SHOULD BE USED ONLY WITH HIGH ALUMINA CEMENT (CIMENT FONDU)

Write for further information. ALAG is available only from:-

LAFARGE ALUMINOUS CEMENT COMPANY LIMITED

73 BROOK STREET, LONDON, W.1. TELEPHONE: MAYFAIR 8546

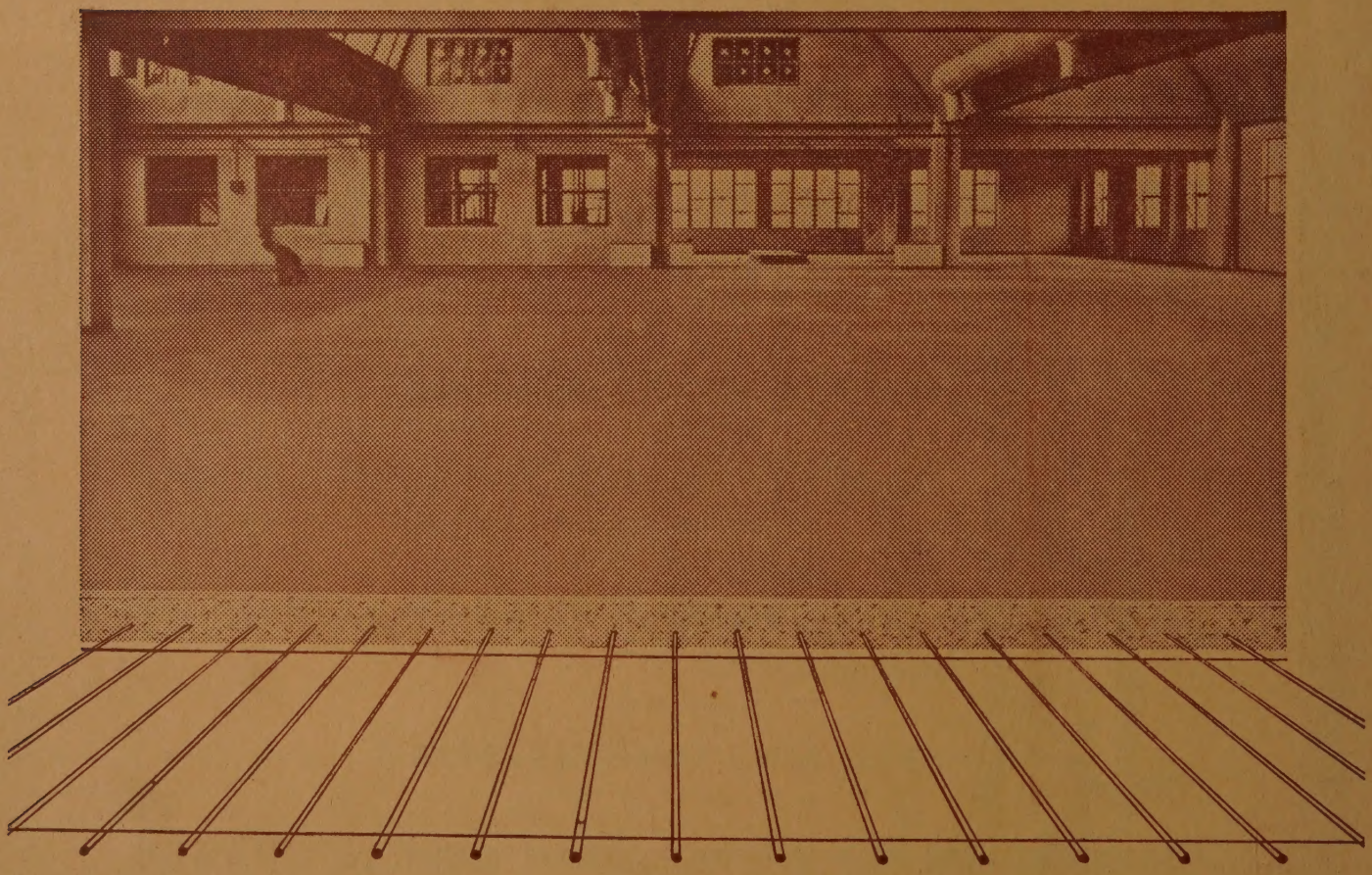


BRC FABRIC

WITHIN A FLOOR SLAB

fulfils the engineers' requirements accurately

Mechanical perfection in the manufacture of BRC electrically welded fabric reinforcement ensures that the exact sectional area per foot width is always maintained.



THE BRITISH REINFORCED CONCRETE ENGINEERING CO. LTD., STAFFORD

London, Birmingham, Bristol, Leeds, Leicester, Liverpool, Manchester, Newcastle, Cardiff, Glasgow, Dublin, Belfast, Bulawayo, Calcutta, Johannesburg, Singapore, Vancouver.

Export Sales: 54 Grosvenor Street, London, W.1

H.W.978